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GEOLOGISTS' ASSOCIATION,

LONDON.

A SKETCH OF THE LATER TERTIARY HISTORY OF EAST ANGLIA,

WITH REFERENCE TO THE LONG EXCURSION,
JULY 26th to AUGUST 4th, 1902.

BY

F. W. HARMER, F.G.S.

With Numerous Illustrations.

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A SKETCH OF THE LATER TERTIARY HISTORY OF EAST ANGLIA.

By F. W. HARMER, F.G.S.

PART I.—THE PLIOCENE PERIOD.

INTRODUCTORY.

THE President of the Geologists' Association has asked me to prepare, for the use of those taking part in the proposed excursion to East Anglia, a résumé of the views I have published in some recent papers on the later Tertiary deposits of the East of England.

The object of those papers was to trace out as far as possible the conditions under which the latter were accumulated, and their relation to each other, rather than to attempt any detailed description of the deposits themselves, a task which had been exhaustively performed by the officers of H.M. Geological Survey. No apology is made therefore for treating the subject in a similar and perhaps a somewhat popular way. On this occasion a bird's-eye view, even if more or less out of focus, may be useful; a working hypothesis, if somewhat speculative, may provoke discussion and lead to further inquiry.

The geological history of the Pliocene epoch forms the introductory chapter to that of our own times, the general features of the British Isles having by that period assumed, more or less, the character under which we know them.

This is also true to a considerable extent of the East Anglian region, although the fact has not always been recognised by geologists. While the latter were discussing such physiographical problems as the depth of the Crag sea, at one stage, it was thought by some, reaching 500 or even 1,000 feet,* the mother wit of the peasants of Suffolk and Essex had led them straight to the heart of the matter. Speculating as to the origin of the beds of "cockle shells" everywhere present, and familiar with the occasional irruption of the tides upon the low-lying lands of the coast, they have often expressed to me their simple explanation: "the sea once came as far as this." They were right, the shores of East Anglia were bathed during the Crag period, as they are to-day, by the German Ocean, which then extended somewhat further to the west. My compatriots do not realize, however, as we now do, that the Rhine and its affluents were

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* *Quart. Journ. Geol. Soc.*, vol. xxvii, p. 135, 1871.

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bringing into it, as they have been ever since, the sediment of which the Pliocene and post-Pliocene deposits of the Anglo-Belgian basin have been built. The more distinctly we can keep these two facts in view, the more easy it will be for us to understand the physical conditions of our later Tertiary history.

The subject must, however, be treated as a whole. The solution of the Pliocene problem cannot be arrived at by the study of isolated sections, or of limited areas. It will be especially necessary, in the first instance, briefly to refer to the Pliocene deposits of Belgium and Holland.

THE OLDER PLIOCENE DEPOSITS OF THE SOUTH OF ENGLAND, AND OF BELGIUM AND HOLLAND.

The researches of Mr. Clement Reid have given us a list of between 60 and 70 species of Mollusca from an Older Pliocene deposit at Lenham, on the North Downs of Kent, 600 ft. above the sea.* These Lenham beds are represented by a portion, at least, of the ferruginous sandstones of Louvain and Diest, with which they are connected by a series of outliers, always on high ground, and often capping isolated hills, as, for example, that of Cassel, in the north of France, which one passes on the left hand, at no great distance from the railway, when travelling from Calais to Lille (fig. 1).

The Diestien sandstones (*Zone à Terebratula grandis* of Belgian geologists) are for the most part unfossiliferous, but about sixty species of Mollusca are known from them. The greater part of these are characteristic Crag forms, but some are of an older type, as, for example, *Pyrula reticulata*, *Cassis saburon*, *Murex scalariformis*, *Conus dujardinii*, *and Pleurotoma intorta*, common in the North Sea in Miocene times, but either unknown from the Coralline Crag, or dying out in that region during the deposition of the latter.

The Lenham fauna is of a similarly mixed character. It includes on the one hand a number of common Crag shells, and, on the other, well-known Miocene or Older Pliocene species, such as *Terebra acuminata*, *Triton heptagonum*, *Fusus lamellosus*, *Pleurotoma consobrina*, *P. jouanettii*, *Cancellaria contorta*, *Hinnites cortesyi*, *Cardium papillosum*, and, in great abundance, *Arca diluvii*. The last species is very common in the Miocene beds of Belgium (Bolderien), but, as far as we know, it had disappeared from the Anglo-Belgian basin before the deposition of

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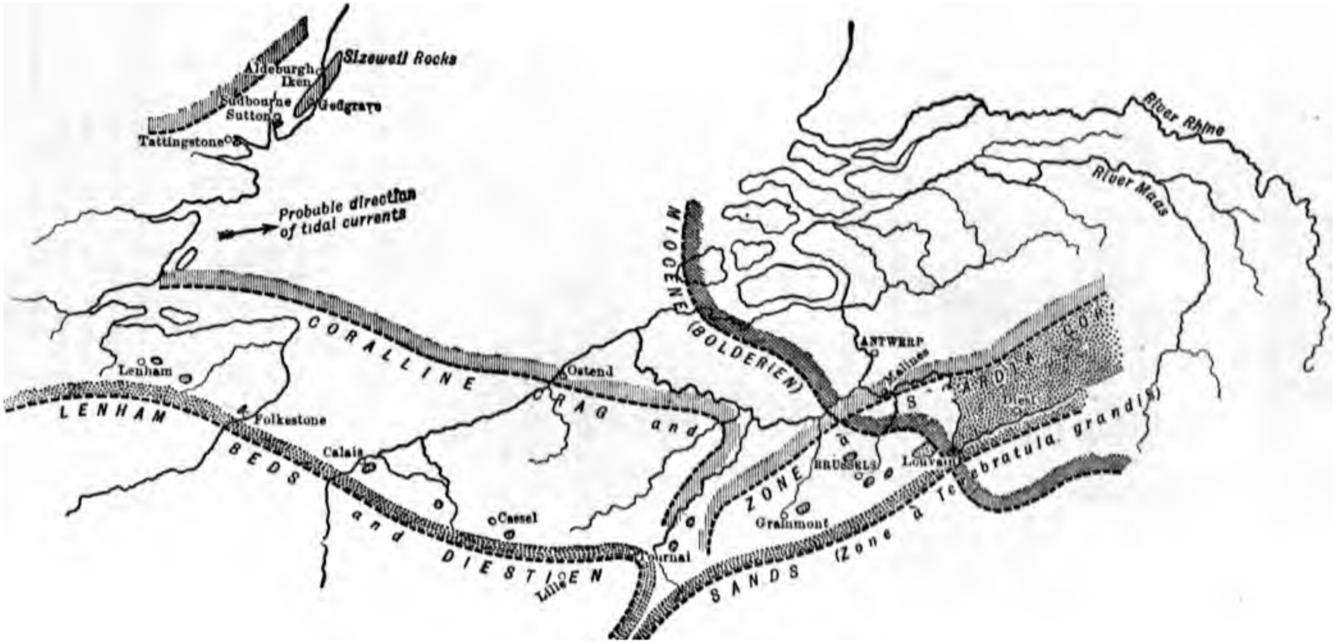
* Pliocene deposits of Britain, Mem. Geol. Survey, p. 236, 1895. The Lenham Beds were first described by Prestwich and S. V. Wood in 1858, *Quart. Journ. Geol. Soc.*, vol. xiv, p. 322.

FIG. 1.—MAP SHOWING THE PROBABLE WESTERN AND SOUTHERN LIMITS OF THE GERMAN OCEAN DURING THE MIOCENE, AND AT THE CASTERLIEN AND DIESTIEN PERIODS. (Scale : $\frac{1}{2{,}500{,}000}$ = about 39 miles to the inch.)

(*Reproduced, with permission, from the Quart. Journ. Geol. Soc., vol. liv, p. 316.*)



the Coralline Crag. On the other hand Astartes, which occur in prodigious numbers in the Coralline Crag, are rare at Lenham.

A third fossiliferous deposit, possibly of similar age, although perhaps somewhat older, occurs at Waenrode, 6 or 7 kilometres south of Diest,* from which fourteen species of Mollusca have been identified, most of them being found in the English Crag.

The Waenrode deposit also contains an admixture, with species of a recent type, of some of an older character, as, for example, *Cassis saburon*, *Pyrula reticulata*, *Cardium subturgidum*, and *Isocardia lunulata*, together with three others, the identification of which is uncertain, referred to the Miocene forms, *Cassis rondeletti*, *Pecten callaudi*, and *Lucina drouetti*.†

We turn now to the fauna of the well-known box-stones, which occur at the base of both the Coralline and the Red Crags, and resemble the rounded pebbles of a modern beach. They are composed of ferruginous sandstone of similar character to that of the Diestien beds, and represent an early stage of the invasion of East Anglia by the Pliocene sea, a basin at that time open to the south and closed to the north. Casts of the following species of Mollusca have been obtained from the box-stones:

Cassidaria bicatenata,
Conus dujardinii,
Nassa conglobata,
Pyrula reticulata,
Trochus zizyphinus,
Voluta lamberti,
,, *auris-leporis*,
Dentalium dentalis,
Cardium decorticatum,
Cyprina islandica,
,, *rustica*,
Glycimeris angusta,
Isocardia cor,
,, *lunulata*,
Panopœa faujasii,
Pecten opercularis,
Pectunculus glycimeris.

Here again we find the same admixture with common Crag forms, of those of an older type, as for example *Conus dujardinii*, *Nassa conglobata*, *Pyrula reticulata*, and *Voluta auris-leporis*. The individual species are not identical in the four cases just mentioned, but this is not remarkable, since the total number is very small, perhaps not one seventh part of the molluscan fauna of the North Sea at that period; their general character is, however, the same, and points to the conclusion that they are approximately of similar, and, I think, of Older Pliocene age.‡

It seems probable that these various deposits of the South East of England and of Belgium had been consolidated and upraised, although not to their present height, before the commencement of the Newer Pliocene period, and that they formed then the southern margin of the Crag sea.

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* *Ann. de la Soc. Malac. de Belgique.* T. 19, p. 29, 1884.

† It should be stated that M. Vanden Broeck considers the Waenrode bed to be of Miocene age

‡ Prof. Ray Lankester took a similar view in 1870. *Quart. Journ. Geol. Soc.*, vol. xxvi, p. 500.

As so few fossiliferous exposures are known, and the total number of specimens is small compared with that of the East Anglian Crag, it is probable that the species obtained represent some of the more abundant fossils of the strata in which they occur. Comparing them with the characteristic Mollusca of the Coralline Crag, their general facies seems to be of an older type than that of the latter; omitting those found only in the bed at Waenrode, the age of which is thought by foreign geologists to be Miocene, they contain 48 per cent. of extinct species, compared with from 36 to 38 per cent. in the case of the Coralline Crag.

THE NEWER PLIOCENE DEPOSITS OF BELGIUM AND HOLLAND.

Casterlien (*Zone à Isocardia cor.*).

Excavations in the low ground near Antwerp (fig. 1). at some distance from the range of hills referred to, have brought to light some fossiliferous deposits to which the name *Zone à Isocardia cor* was given in 1874, by M. Cogels. They were formerly regarded as equivalent to the ferruginous sandstones of Louvain and Diest, but M. Vanden Broeck considering them, and I think with reason, to be newer, has called them Casterlien. Although the number of species obtained from the latter is considerably smaller than that from the Coralline Crag, the correspondence between the two deposits is so close that they are doubtless of similar age. One difference, however, should be noticed. The glauconiferous sands of Antwerp represent, in M. Vanden Broeck's opinion, an undisturbed sea bottom; their lamellibranchiate Mollusca are found with both valves united, and apparently in the position of growth. The Coralline Crag, on the contrary, is composed of drifted sediment, almost entirely organic, consisting of shells or Polyzoa,* and of material derived from their decomposition.

The Casterlien deposits differ, moreover, from the Coralline Crag in that they contain in prodigious numbers, the fossil remains of marine Vertebrata, especially of cetaceans, pinnigrades and cartilaginous fishes.

Referring to the wonderful collections in the Museum at Brussels, Mr. Vanden Broeck says:—

"D'énormes grillages, adossés aux murailles de certains vestibules, contient plus de deux cents mètres cubes d'ossements de cétacés, provenant du déchet des doubles, et qui ont été ainsi réunis afin de donner au visiteur étonné, une idée de l'incroyable quantité de baleines qui hantaient le golfe d'Anvers à cet époque. Si nous ajoutons encore, qui l'on peut évaluer à 50,000, le nombre d'échantillons choisis d'ossements de vertébrés qui se trouve actuellement exposés au musée, il nous restera, croyons-nous, plus rien ajouter à ce sujet."*

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* Polyzoa of similar species to those of the Coralline Crag are found in great abundance in the neighbourhood of Antwerp, in beds considered to be equivalent to the *Sables à Isocardia cor.*

Our bird's-eye view of the history of the Pliocene period would be incomplete without a passing reference to these mighty denizens of the Crag sea, which, although not known from our English deposits, must have visited from time to time the East Anglian coasts.

The vertebrate fauna of the German Ocean at this period was extraordinarily rich, but it cannot be supposed that marine animals could have existed at one spot in numbers corresponding to those of these Antwerp fossils. As M. Vanden Broeck remarks, the Gulf of Antwerp must have been a veritable cemetery. A possible explanation of the facts may be that a series of sand banks then lay off the Belgian coast, and running more or less parallel to it. During the prevalence of north-westerly gales, cetaceans or sharks might have been stranded on these banks, and afterwards carried over into the deeper water between the latter and the land, where they would have been caught as in a trap, unable to escape. That the fossil skeletons of such animals are not found in the English Crag seems to indicate that the epoch of easterly gales in the Crag region alluded to on p. 22 had not yet commenced.

Deep borings in Holland, the details of which we owe to my friend Dr. J. Lorié, of Utrecht†, shew that the Casterlien deposits‡ extend northwards under the more recent strata of that country, dipping as well as thickening as we trace them in that direction. They are more than 300 ft. in thickness at Utrecht, the boring at that place being carried to a depth of 1,200 ft. without penetrating them (fig. 2). The beds reached in these Dutch borings, now eight in number, show an entire absence of the characteristic Miocene and older Pliocene Mollusca before alluded to, which give an older facies to the deposits of Lenham and Diest. It is a significant fact that not a single species has been recorded by Dr. Lorié of an earlier type than that of the Coralline Crag, or the Casterlien of Antwerp.

Scaldisien (*Zone à Trophon antiquum*).

Overlying the Casterlien strata in the neighbourhood of Antwerp, are some stratified sands containing drifted shells, for which M. Cogels proposed in 1874 the term *Sables à Trophon antiquum*; but which are now generally known as Scaldisien. They are specially characterized by the abundance of the sinistral form only of the common whelk, from which they take their name. In this the Scaldisien resembles the Crag of Walton-on-the-Naze, as it does in the almost exclusively southern character of its molluscan fauna, and the two deposits are no doubt synchronous. The Scaldisien strata may also be traced northwards into Holland, dipping and thickening in that direction as do the Casterlien beds (fig. 2).

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* M. Vanden Broeck gives a list of 17 species of cetaceans, 16 of pinnigrades, and 30 of sharks &c., from these deposits. *Esq. Geol. des dep. Plioc. d'Anvers, Bruxelles*, 1876, p. 120.

† *Contr. à la Geol. des Pays-Bas archives Teyler*, Ser. 2. 1885.

‡ Alluded to as Diestien in my paper on "The Pliocene deposits of Holland." *Quart. Journ. Geol. Soc.*, vol. lii, p. 748, 1896.

In Belgium, where they attain no great thickness, the Scaldisien beds probably represent the marginal deposits of the south-eastern shores of the Crag sea, but at Utrecht, where they are 120 ft. thick, they may indicate an undisturbed sea bottom.

An upper zone of the Scaldisien, the Poederlien of M. Vincent, containing a fauna practically identical with that of the former, except that it contains a few northern shells, as for example *Trophon* (*Neptunea*) *antiquus* (dextral), *T. despectus*, and *Pecten islandicus*, seems to be more or less the equivalent of the Oakley horizon of the Walton Crag, to be described hereafter.

Overlying the Scaldisien strata at Utrecht, and reached also in borings at Amsterdam, are some beds, 500 ft. or so in thickness at the latter place (see fig. 2), which contain arctic shells, as for example, *Cardium groenlandicum* and *Leda lanceolata*, species unknown from the Scaldisien, or at the earlier horizons of the Red Crag. Until 1896, these deposits had been grouped with the Scaldisien, but in that year I proposed, in consultation with Dr. Lorié, to call them Amstelien.*

Since the deposition of the Lenham Crag and of the sands of Louvain and Diest, the south of England has risen more than 600 ft., the elevatory movement having been gradually less eastwards, in the direction of Belgium. The present elevations of the base of the Pliocene above O.D. are Lenham 600 ft., Cassel 515 ft., Grammont 375 ft., Brussels 235 ft., and Diest 205 ft. On the other hand, subsidence has taken place in Holland, regularly increasing northwards towards Amsterdam, where it may have amounted to 1,500 ft. Between the end of the Older Pliocene period and the present day the Anglo-Belgian basin has moved as on a pivot, rising in the south and sinking in the north. The maximum disturbance may have extended along a line drawn from Kent to Amsterdam, dying away to the east and west.

This earth movement may be traced also in East Anglia, and it furnishes us with a clue towards the elucidation of the Pliocene history of that district.†

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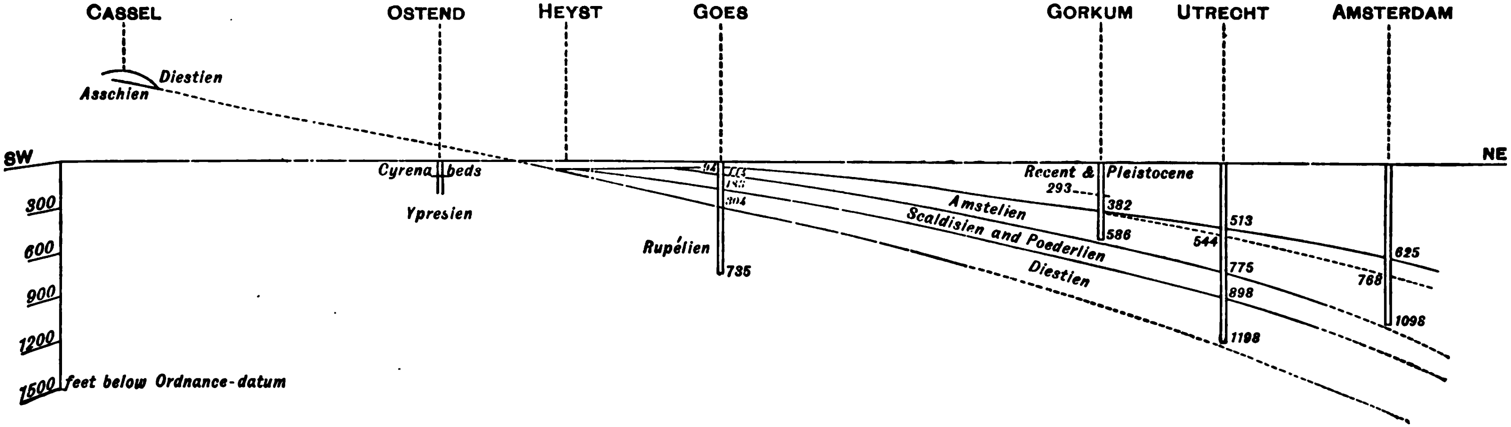
* *Quart. Journ. Geol. Soc.*, vol. lii, p. 763.

† This subject is more fully dealt with in my paper "On the Pliocene deposits of Holland." *Quart. Journ. Geol. Soc.*, vol. lii, p. 748, 1896.

FIG. 2.—SECTION FROM CASSEL TO AMSTERDAM.

(*Reproduced, with permission, from Quart. Journ. Geol. Soc., vol.* lii, *p.* 761.)



The beds shown in the above section as Diestien in the borings at Utrecht and Goes, are those which M. Vanden Broeck now calls Casterlien (*Zone à Isocardia cor.*). Those of Cassel are Diestien (*Zone à Terebratula grandis*). If the latter are present at Utrecht, it is at a still lower level.

THE NEWER PLIOCENE DEPOSITS OF EAST ANGLIA

The Coralline Crag. Gedgravian.

I have recently given my reasons[1] for disagreeing with many of the conclusions reached in Prestwich's well-known memoir on the Coralline Crag, and especially with his division of this formation into eight zones, characterized by important changes in the physical and climatal conditions of the period,* as for example that, at one stage, floating ice may have existed in the North Sea, and that at another, that sea may have attained a depth of 1,000 ft. in the Suffolk area.[2] Such a depression would have submerged a large part of the East of England, of which there is no evidence, and which seems most improbable. The view taken by S. V. Wood, Junr., and myself, that the fossiliferous sands of the lower part of the Coralline Crag should be separated from the indurated ferruginous rock of the upper portion† is also untenable in the light of our present knowledge. The latter beds are merely an altered condition of the former.

As pointed out by Mr. P. F. Kendall‡, shells composed of aragonite, a group including most of the Crag Mollusca, have been removed from the decalcified part of the Crag by the infiltration of water containing carbonic acid, while the calcite shell, as for example, *Pecten* and *Terebratula*, with Echinoderma and Polyzoa, have been preserved. With the exception of the nodule bed at its base, the Coralline Crag is, I believe, one deposit, representing one or more of a series of submarine banks which formerly fringed the western margin of the North Sea, at no great distance from it, like those now existing along the eastern coasts of Norfolk and Suffolk.

The southern facies of the molluscan fauna of the Anglo-Belgian basin not only during the deposition of the Lenham beds, but also of the Coralline Crag,§ and its resemblance to that of the Mediterranean, past or present, points, I think, to the conclusion that the Crag area communicated with the Atlantic, up to the end of the latter period, by means of a strait over some part of the south-east of England, possibly as shewn in fig. 1.||

If, moreover, the Coralline Crag sea was a basin more or less

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[1] * *Quart. Journ. Geol. Soc.*, vol. liv, p. 320. 1898.

[2] * *Quart. Journ. Geol. Soc.*, vol. xxvii, p. 135. 1871.

† Supp. to "Mollusca of the Crag," Pal. Soc., p. iii. 1872.

‡ *Geol. Mag.*, Dec. 2, vol. x, p. 497. 1883.

§ As to the supposed existence of northern forms in the Coralline Crag (*Quart. Journ. Geol. Soc.*, vol. liv, p. 346), according to my view, the northern species of Mollusca in this formation are only about one per cent. of the whole.

|| It must not be forgotten the south of England stood at a much lower level during the Lenham period. The fossiliferous deposits of Gourbesville, near Carentan (*Conglomérat à Terebratules des Bohons, Dollfus, Esq. des Terr. Tert. de la Normandie, Mem. Soc. Geol. de Norm.*, p. 39, 1880) which contains an admixture of Crag species with those of an older type, such as *Terebra basteroti*, *Mitra aperta*, *Leda pella*, &c , may be of similar age to the Lenham bed, and indicate the direction in which the Anglo-Belgian basin, in older Pliocene times, communicated with the Atlantic.

closed to the north, as seems probable from the absence of the boreal Mollusca which afterwards invaded the region, the strongest tidal currents, those of the flowing tide, would have come from the south-west, and not from the north, as at present in the North Sea.

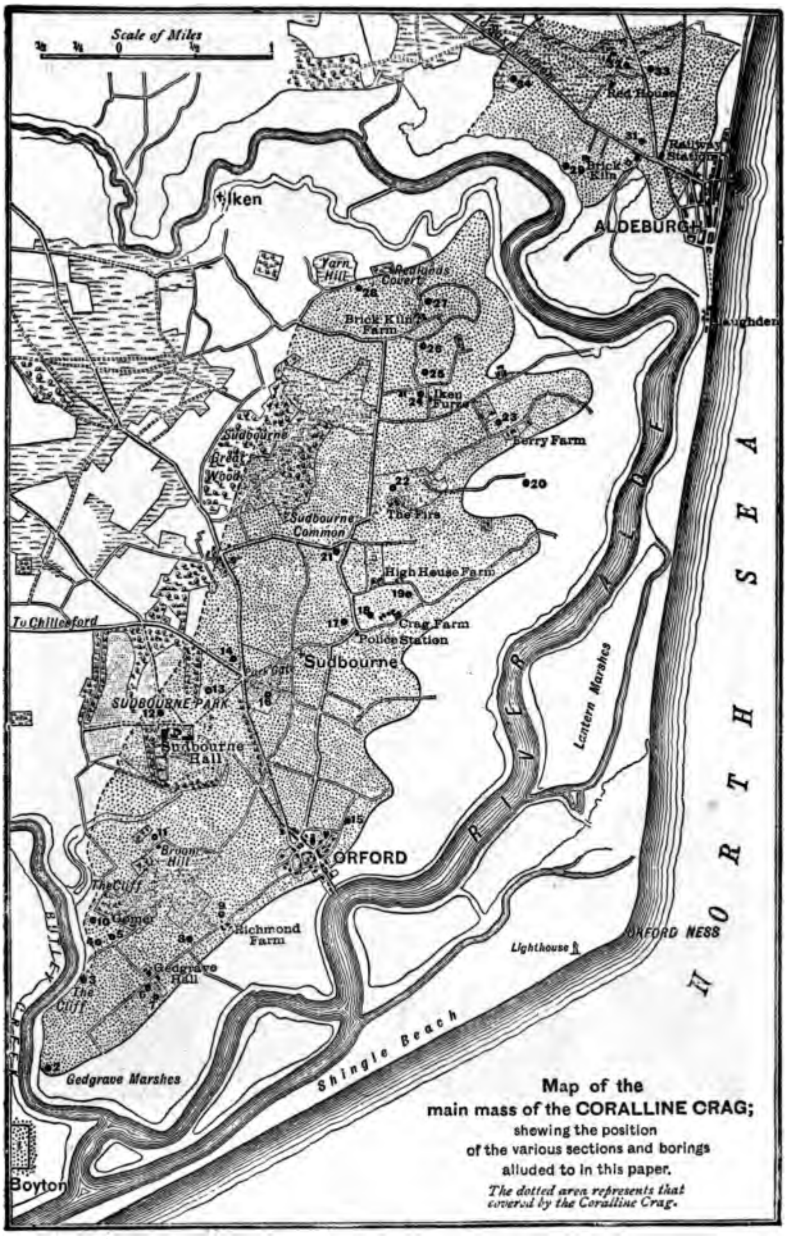
Composed almost entirely, as already stated, of organic material, the Coralline Crag banks may have originated under the influence of such currents. Where the latter ran strongly no deposition took place, but shells and shell fragments swept up from the bottom, would collect in comparatively sheltered positions. Such conditions prevail now in the northern part of the Irish Sea, where an accumulation of dead shells on the Turbot bank, off the coast of Antrim, is caused by the tidal currents which sweep with much velocity through the narrow channel separating Ireland from Scotland. Similar deposits of organic material, called by Professor Herdman "neritic," and due to the strong currents which run through the Calf sound, exist near the southern extremity of the Isle of Man.

Prestwich attached importance to the occurrence, at certain places in the Coralline Crag, of layers of large shells, such as *Cyprina islandica*, which he considered distinctive of special zones in it, other beds being characterized by the presence of smaller shells. The species referred to has, however, existed in the North Sea from Miocene times to the present day, possibly without intermission, so that its presence or absence at any spot must be accidental. It is not probable that at one period the sea-bottom of the North Sea was for some miles continuously covered with a layer of the dead and drifted shells of *Cyprina* and other large Mollusca, and that these species then disappeared for a time from the Crag area. Shells are sorted out by currents of varying strength as pebbles are in beds of gravel; small specimens would therefore have accumulated in one place, larger ones in another, and comminuted shells, or fine calcareous sand in a third.

We can understand, moreover, on this view, that when, by a temporary and local diversion of the currents, no sediment was for a time deposited on any part of the Coralline Crag banks, they would have become occupied by colonies of reef-building Polyzoa, which flourish best in clear water agitated by currents; but such colonies would have been smothered and unable to exist when another alteration of the current brought over them quantities of the fine mud. Crustaceans and echinoderms could, however, have lived on the Crag banks, and here and there a few Mollusca might have established themselves, but their numbers would have been small in proportion to the drifted shells, as at present on the Turbot Bank. There is no evidence of an undisturbed sea bottom, still less of deep sea conditions, as suggested by Prestwich, uninfluenced by currents, in any part of the

FIG. 3—MAP OF THE MAIN MASS OF THE CORALLINE CRAG.

(Reproduced, with permission, from Quart. Journ. Geol. Soc., vol. liv, *p.* 326.)



Map of the
main mass of the **CORALLINE CRAG;**
shewing the position
of the various sections and borings
alluded to in this paper.

The dotted area represents that covered by the Coralline Crag.

Note —The position of pit 30 should have been indicated just below the letter K (in 'Kiln'), due west of Aldeburgh.

Coralline Crag. With the few and the local exceptions just mentioned, the fossil Mollusca are those of dead and drifted organisms. That definite and persistent zones should exist in a sand bank, composed of constantly shifting materials, seems improbable. No serious attempt has been made to work out stratigraphically the proposed divisions.

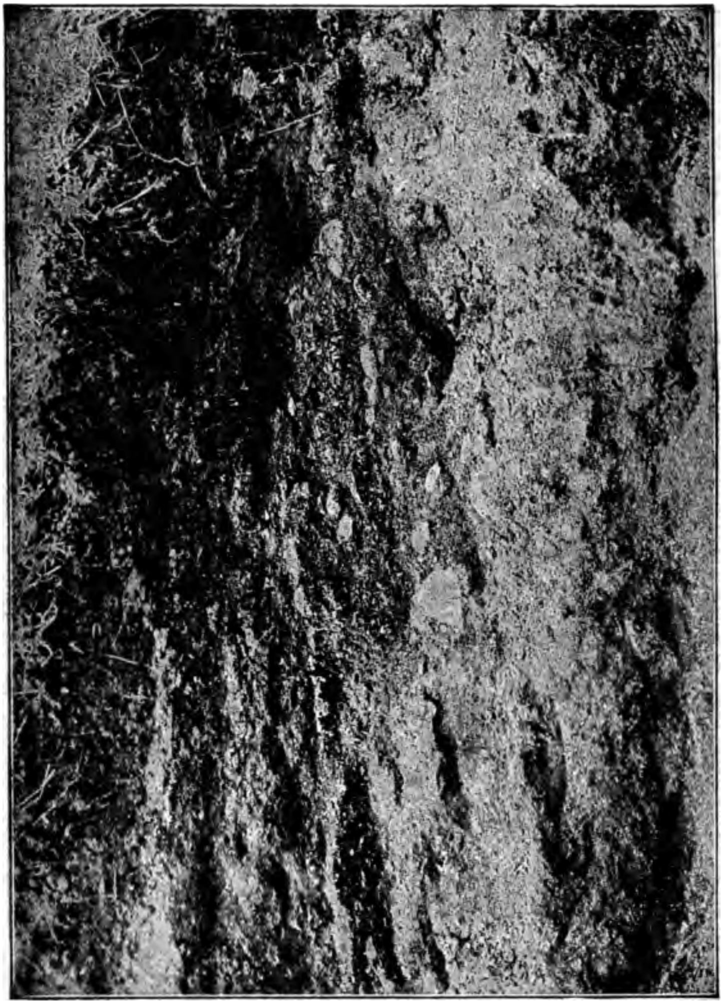


FIG. 4.—SECTION IN GANGWAY LEADING DOWN TO BULLOCK YARD PIT, IKEN.

(*Reproduced, with permission, from Quart. Journ. Geol. Soc., vol.* liv, *p.* 340.

[Here a lenticular seam of shelly sand, with perfect shells and comminuted shell-fragments, is included in the ferruginous rock of the highest part of the Coralline Crag.]

For the convenience of members of the Association hereafter visiting the Coralline Crag of the Orford and Aldeburgh districts, the map, fig. 3, showing the position of the more interesting sections, is reproduced.

The fossiliferous sands may be best studied from Orford, where there is a comfortable inn, the "Crown and Castle." A visit to pits 11 and 12 is recommended for the collection of Mollusca. Pits 14 and 18 show the Crag in its decalcified condition, and contain many Polyzoa. In pit 19, the superposition of the Red upon the Coralline Crag may be seen.

Aldeburgh is a good centre for the study of the indurated Crag. From pits 30 and 33, many species of Polyzoa may be obtained; 31 contains a layer of the casts of the large aragonite species, *Cardium decorticatum*, *Panopœa faujasii*, *Voluta lamberti*, and others, the calcareous matter of the shells having been completely removed. At Iken, in pit 27, there is an interesting exposure showing a small lenticular mass of the unaltered shelly Crag, in the midst of the ferruginous rock. As the fossils it contains, *Cyprina*, *Cardium*, *Venus*, *Cardita*, &c., can be obtained in large quantities at Sudbourne and Orford, it is earnestly requested that this important and absolutely unique section, of which a photograph is here given (fig. 4), may remain untouched. Many specimens of Polyzoa and echinoderms can be found in pit 14 at Iken.

Sutton, some miles to the south-west, is a good locality for both Coralline and Red Crag fossils. Most of S. V. Wood's specimens came from that place.

Some borings I have recently made in the Coralline Crag show that the surface of the London Clay, upon which it rests, dips rather rapidly, from 8 to 10 feet per mile, towards the north-north-east. This must be borne in mind when comparing one section with another. The bed with large shells at pit 11, for example, seems to be on the same level as that containing similar fossils at pit 12, but this is not the case, as between the two places the base of the Crag dips eight or nine feet (fig. 5).

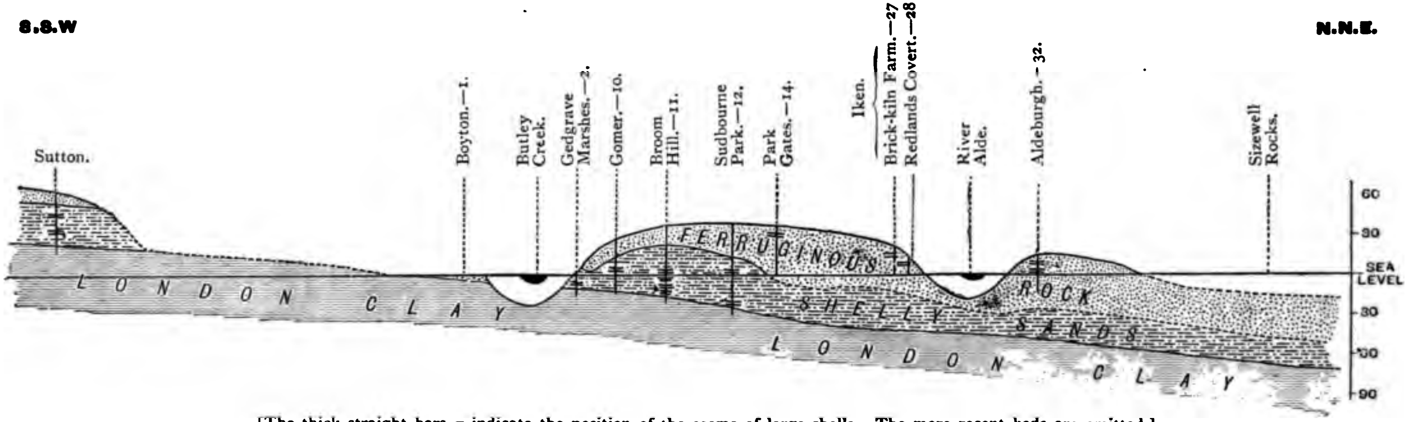
The larger proportion of the Mollusca known from the Coralline Crag are exceedingly rare in that formation, a number of them having been known to Searles V. Wood from unique, or at the most, from very few specimens only. A consideration of a list of its more abundant and characteristic species brings out clearly two points; the preponderatingly southern character of the fauna, and its close relation to that of the Waltonian zone.

The Red Crag. Waltonian, Newbournian, Butleyan.

The term Red Crag, including, as it does, beds having a widely different fauna, and probably differing, as it seems to me, considerably in age is vague, and when we attempt to correlate the East Anglian deposits with those of other countries, incon-

FIG. 5.—SECTION SHOWING THE STRUCTURE OF THE CORALLINE CRAG (ACCORDING TO THE PRESENT WRITER) AND THE PROGRESSIVE DIP OF ITS JUNCTION WITH THE LONDON CLAY TOWARDS THE N.N.E.

(Reproduced, with permission, from Quart. Journ. Geol. Soc., vol. liv, *p.* 328.*)*



[The thick straight bars = indicate the position of the seams of large shells. The more recent beds are omitted.]

venient. The Scaldisien of Belgium, with its southern shells, may represent one part of it (the Walton Crag), and the Amstelien of Holland, in which arctic species are common, another. It seems desirable, therefore, while retaining it for general use, to adopt for its various horizons some more definite and distinctive names.

The following classification of the Pliocene strata is that proposed by me in 1900,* except that in deference to the opinion of my friend, Mr. H. B. Woodward, I have now grouped the Norwich, Chillesford, and Weybourne horizons as Icenian.†

The view taken by Prestwich that all the Red Crag deposits are of the same age appears, at first sight, not unreasonable, though it is not so easy to understand why those of the Norwich Crag should have been grouped with them. As to the former, many of their characteristic Mollusca occur in every part of the formation, so that lists of fossils from different localities present more or less resemblance.‡ Such species, however, are not equally common everywhere ; some of them seem to have been dying out at certain horizons, while others, generally recent or northern, were appearing for the first time, or becoming more abundant. The Red Crag deposits arrange themselves in horizontal, and not in vertical sequence, assuming a more recent and a more boreal character as we trace them towards the north. Moreover, the beds I have classed as Waltonian, Newbournian, and Butleyan, each possessing a distinctive fauna of its own, do not overlap. Taking, for example, the three cliff sections of Walton, Felixstowe, and Bawdsey (fig. 6), at each of which the whole thickness of the Crag is, or has been exposed to its junction with the London clay, we find no Waltonian Crag underlying the Newbournian at Felixstowe, nor Newbournian below the Butleyan at Bawdsey. Similarly, the Norwich Crag is not known to rest on the Red Crag. The former has been pierced in borings at Beccles and Southwold, and found to be, at those places, 80 ft. and 147 ft. in thickness respectively, but the fossils obtained were throughout of the usual Norwich Crag type.§

At the close of the Gedgravian (Coralline Crag) period, an aelevtion of the Crag area took place, causing some denudation of the shelly sands, apparently greatest towards the south, as the outliers of Coralline Crag in that direction are small, and probably fragmentary.|| The basement bed of the formation, consisting of chalk flints, box-stones, phosphatic nodules, and other

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* *Quart. Journ. Geol. Soc.* vol. lvi, p. 708.

† The term Icenian was originally proposed for the Pliocene strata by S. P. Woodward, " Manual of the Mollusca," 1856, p. 400.

‡ As will be seen further on, p. 22, this argument might with equal justice be used to prove an identity between the Coralline Crag, and that of Walton.

§ A recent boring at Lowestoft, for the particulars of which I am indebted to Mr. Whitaker, shows 170 ft. of Chillesford Beds and Norwich Crag, on London Clay, under about 70 ft. of drift. The Chalk was reached at 475 ft.

|| If the Coralline Crag originated as a series of submarine banks, however, it may never have covered a considerable area with a continuous sheet, as formerly supposed.

PROPOSED CLASSIFICATION OF THE PLIOCENE DEPOSITS OF THE EAST OF ENGLAND.

NEWER PLIOCENE.

CROMERIAN.		So-called Forest-bed of the Cromer and Kessingland Coast. Zone of *Elephas meridionalis*. Estuarine and freshwater.	
ICENIAN.		Weybourne and Belaugh Crag. Marine. Zone of *Tellina balthica*.	
		Chillesford beds. Estuarine. Zone of *Leda oblongoides*.	
	Norwich Crag Marine.	Upper division— Zone of *Astarte borealis*. Lower division— Zone of *Mactra subtruncata*.	
BUTLEYAN.	Red Crag Marine.	Butley and Bawdsey Crag. Zone of *Cardium groenlandicum*.	Amstelien, Upper portion.
NEWBOURNIAN.		Newbourn and Sutton Crag. Zone of *Mactra constricta*.	Lower portion.
WALTONIAN.		Oakley horizon. Zone of *Mactra obtruncata*.	Poederlien.
		Walton horizon. Zone of *Neptunea contraria*.	Scaldisien.
GEDGRAVIAN.		Coralline Crag. Zone of *Mactra triangula*.	Casterlien.

OLDER PLIOCENE.

LENHAMIAN.	Lenham beds. Zone of *Arca diluvii*. Boxstone fauna.	Diestien **Waenrode beds.**

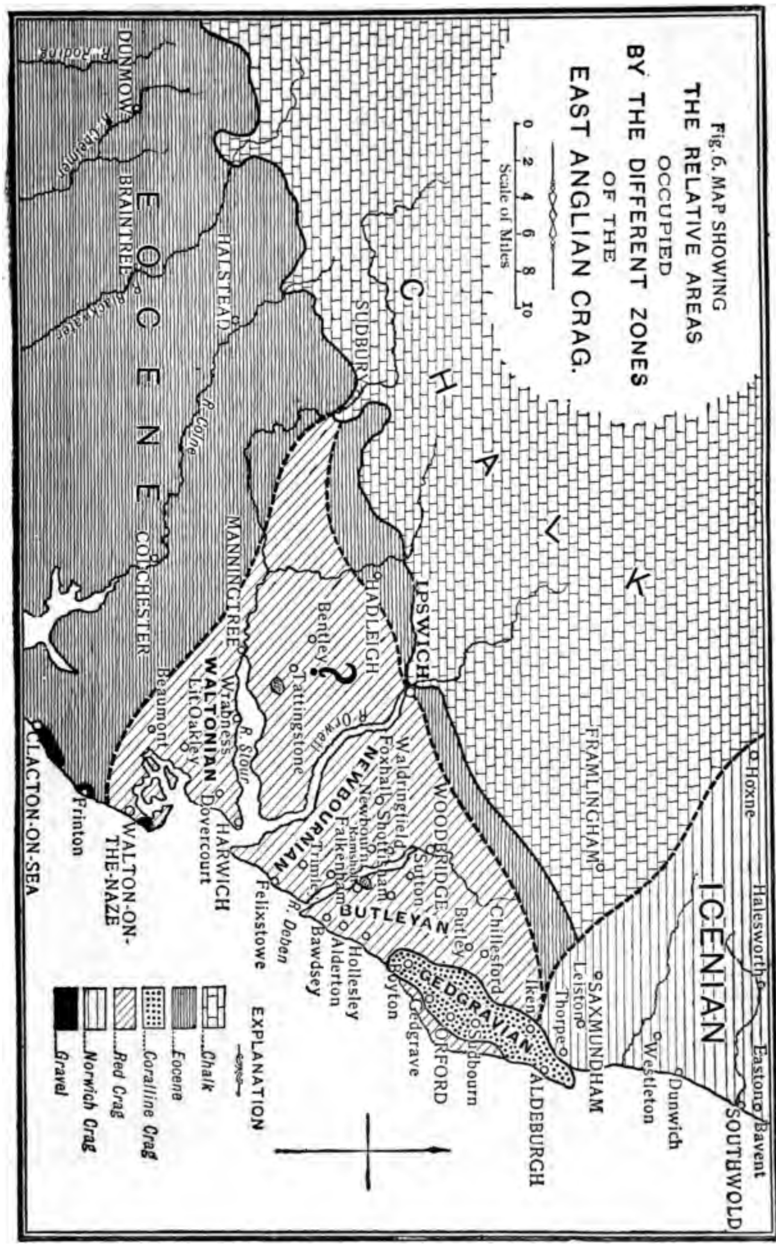


Fig. 6. MAP SHOWING THE RELATIVE AREAS OCCUPIED BY THE DIFFERENT ZONES OF THE EAST ANGLIAN CRAG.

(Reproduced, with permission, from Quart. Journ. Geol. Soc. vol. lvi, p. 714.)

Note: **South of the River Stour the Red Crag has been much denuded.**

derivatives, better able than the incoherent sands to resist the wear and tear of marine denudation, were preserved, and went to form the basement beds of the Red Crag. The sources from which these materials were originally derived must have been cut off before the commencement of the Red Crag epoch, as they rarely occur except in the lowest parts of those deposits. The elevation of the southern part of the Pliocene area to which this was due, interrupted, at the same time, the communication between the North Sea and the English Channel which had previously existed.

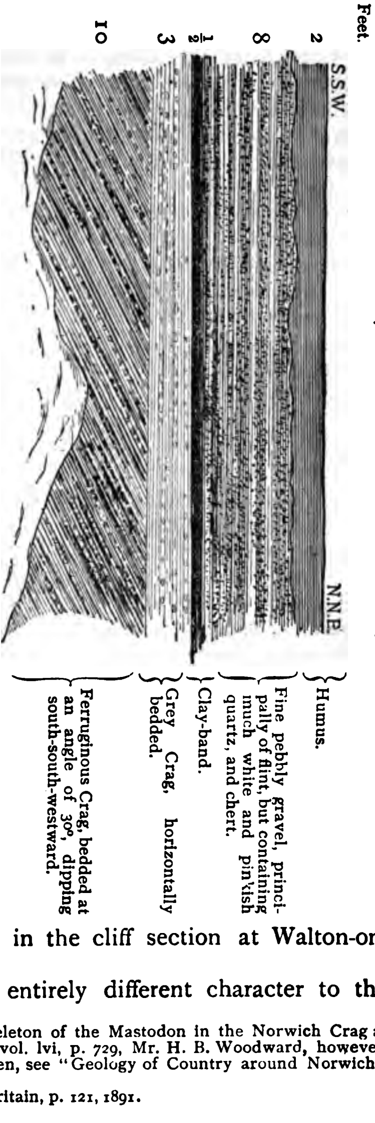
The mammalian remains of these basement beds, equally with the boxstone Mollusca with which they occur, are, I consider, derivative from some Older Pliocene or Miocene deposits formally existing to the south, and were brought into the Crag area by currents, or by the northerly travel of the beach, the basement bed of the Coralline in which they were originally imbedded having been reconstructed by the Red Crag sea. This view removes the difficulty of supposing that animals of an older and southern type, such as *Mastodon*, continued to live in East Anglia, not only during the Coralline and Red Crag periods, but during the Norwich Crag stage also, co-existing with the recent molluscan fauna of the latter, and with arctic shells like *Astarte borealis*, *Cardium groenlandicum*, and *Tellina lata*. No remains of *Mastodon* have been found in the closely connected estuarine (Forest-bed) deposits of the Cromer coast, although the great river to which these were due drained an area far to the south of Great Britain.

The want of correspondence between the mammalian fauna obtained from the nodule and stony beds at the base of the Crag, and that of the Forest-bed, points strongly to the derivative character of the former. Among the larger forms, two or three only are common to both horizons, although the latter are stratigraphically so closely connected. The boxstone fauna is distinctly of an older type than that of the Forest-bed. Compare, for example, *Ursus arvernensis*, *Sus palæochærus*, and *Rhinoceros scheiermacheri* of the former with *U. spelæus*, *S. scrofa*, and *R. etruscus* of the latter. The boxstone fauna includes, moreover, extinct forms such as *Hyænarctos*, *Ailurus*, *Xiphodon*, *Hipparion*, *Tapirus*, *Hyracotherium*, *Coryphodon*, and three species of *Mastodon*. In the Forest-bed, we find on the contrary the red deer, *Cervus elaphus*, and a number of rodents and insectivores, which are still living in Great Britain. The vertebrate fossils of the sea tell the same story. About forty species of marine Mammalia have been recorded from the base of the Crag, all extinct; nine have been found in the Forest-bed, and all but one are recent. Of the birds, reptiles, and fishes of the Forest-bed, 25 in number, only one is not known living, while of the Crag species, 24 out of 32 are extinct. Some of the Crag fossils are Eocene, and therefore clearly derivative; but there is no more evidence for the existence of *Mastodon* in East Anglia in the Newer Pliocene period than of *Coryphodon* or *Hyracotherium.*[*]

Mr. E. T. Newton, estimates the percentage of living vertebrates in the nodule beds at 8.8 per cent., and in the Forest-bed at 69.2 per cent.,[†] too great a difference, I think, to be explained on any other theory than that the former are principally derivative.

The Red Crag deposits rest against, rather than upon the Coralline Crag. There is a well-known case at Sutton where a colony of *Mytilus* is shown to have attached themselves, in Red Crag times, to an old shore line of Coralline Crag, possibly within tide marks. The Coralline Crag outlier of Sutton, together with the principal mass of the formation extending from Gedgrave to Aldeburgh, seem to have formed islands in the Red Crag Sea, and this gives us a datum line, twelve miles in length from south-west to north-east, by which we may fix, with some approach to accuracy, the depth of the water in which the Red Crag originated. Moreover, much of the latter is bedded at a continuous angle of about 30°, as, for example, in the cliff section at Walton-on-the-Naze (fig. 7).

FIG. 7.—SECTION AT WALTON CLIFF.


Feet.
2
8
1
2
3
10
S.S.W.
N.N.E.
Humus.
Fine pebbly gravel, principally of flint, but containing much white and pinkish quartz, and chert.
Clay-band.
Grey Crag, horizontally bedded.
Ferruginous Crag, bedded at an angle of 30°, dipping south-south-westward.

(Reproduced, with permission, from Quart Journ. Geol. Soc., vol. lvi, p. 711.)

This stratification, of an entirely different character to the current bedding of the Coralline Crag, indicates, as pointed out by S. V. Wood, Jun., in 1864,* a deposit formed against a beach, or foreshore, or the edges of a shoal.

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[*] As to the alleged discovery of a skeleton of the Mastodon in the Norwich Crag at Horstead, see *Quart. Jour. Geol. Soc.*, vol. lvi, p. 729, Mr. H. B. Woodward, however, does not agree with the view there taken, see "Geology of Country around Norwich," Mem. Geol. Survey, 1881, p. 57.

[†] Vertebrata of the Plioc. Dep. of Britain, p. 121, 1891.

The frequent south-south-westerly dip of the highly inclined laminæ, as in the above case, shows, however, that the Red Crag was not wholly accumulated against the southern shore of a sea gradually retreating towards the north and the east, or the dip would have been prevalently in the other direction, viz., to the north-east. The tectonic movement which affected East Anglia must therefore have taken the form, not so much of continuous subsidence in one direction, and upheaval in another, as of a succession of foldings which shifted the area of deposition from time to time towards the north or north-east. In this way a series of land-locked bays were formed, one after the other, which were successively silted up by sediment, deposited partly against the shore, and partly as banks or shoals in shallow water. Under such circumstances, the shelly beds so formed would dip in different directions on the opposite sides of the bays.

There is an area immediately to the south of the Hook of Holland, which seems to represent the condition of East Anglia during the Red Crag period. What was formerly a bay or inlet is now nearly choked with shelly sand, which is still accumulating on the edges of the shoals, in channels formerly occupied by the River Maas, often bedded at a high angle, the stratification dipping in different directions as it follows the sinuous winding of the banks.

The position which these bays of the Red Crag period successively occupied may be approximately defined. A reference to the map (fig. 6) will show what I consider to be the geographical divisions of the Crag, indicated by the differing character of their molluscan fauna.†

One difficulty in working out the Crag history perplexed me for many years, and it is only recently that a probable explanation has suggested itself.

At present dead shells are but seldom met with on the eastern shores of Norfolk and Suffolk. One may walk for a mile along the beach at Yarmouth, or Lowestoft, without finding more than a chance specimen. That this is not due to any absence of molluscan life from the adjoining sea, my son, Dr. Sidney F. Harmer, and I have proved by dredging.

During a visit in 1899 to Hyères, in the south of France, I noticed that of the two low sandy beaches fringing the isthmus which connects the peninsula of Giens with the mainland (fig. 8), that to the west, several miles in length, was covered from end to end with the shells of dead molluscs, while upon the beach facing the east not a single shell was to be found. The reason for this was obvious, the N.W. mistral was blowing upon the former, causing considerable surf, while upon the other, protected as it was by the isthmus, the water was perfectly calm.

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* *Ann. and Mag. of Nat. Hist.*, March, 1864.

† The fauna of the Red Crag District, lying between the rivers Stour and Orwell, has not at present been worked out carefully.

(*Reproduced, with permission, from Quart. Journ. Geol. Soc., vol. lvii, p. 407.*)

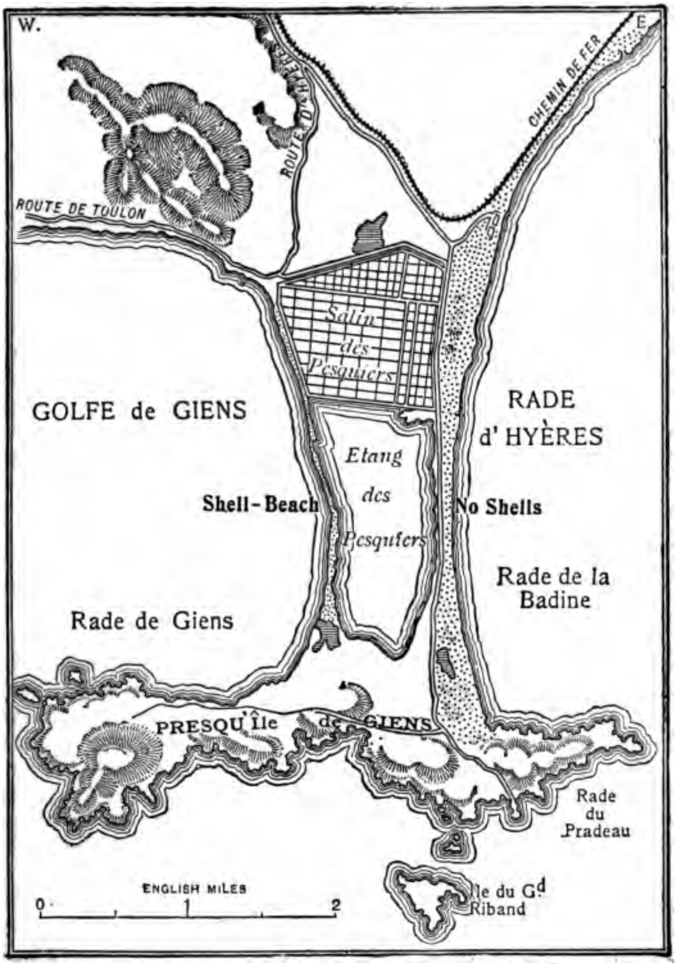

FIG. 8.—MAP OF THE LOW ISTHMUS CONNECTING THE PRESQU'ILE DE GIENS WITH THE MAINLAND.

The sea is agitated during storms to a greater or less depth, according to their violence, and the size of the waves they cause. Mollusca are at such times rooted up from their usual habitats. Being moved along the bottom in the direction towards which the wind is blowing, they finally accumulate on the opposing beach. At present most of the winter storms prevalent in East Anglia are attended by westerly winds, as the centres of the cyclonic disturbances to which they are due pass away to the north or northwest of Great Britain. The shell beaches of the British Isles principally occur therefore on our west coasts. Enormous quantities of dead molluscs are blown, however, towards the shores of Holland. Shells lie, in fact, as thickly on the beaches and in the estuarine inlets of the Dutch coast as they did on those of East Anglia during the Red Crag period.[*] Easterly rather than westerly gales must, therefore, have then been prevalent in the Crag area. I have endeavoured to show elsewhere, by a study of the Meteorology of the later Pliocene epoch, that this may have been the case, the prevalent storm tracks then lying further to the south.[†]

It is not difficult to understand, when standing on the cliff a Dovercourt, looking out to sea over the bay formed by the projecting headlands of Walton-on-the-Naze on one side, and of Felixstowe on the other, that it would need only the prevalence of strong easterly winds to reproduce there the conditions of the Red Crag period. Were the direction of the winter gales which now drive vast quantities of sand and dead shells on to the shores of Holland, turned towards Essex, the mud flats of Dovercourt Bay would soon become silted up with shelly sand, as was that of the Waltonian region at a former period.

The Coralline Crag has been hitherto referred to the Older, and the Red Crag, including the Walton zone, to the Newer Pliocene, the former being regarded as equivalent to the Piacenziano of Italy.[‡]

At the time of the publication of Wood's "Supplement to the Mollusca of the Crag," there seemed good reason for this classification, more than half of the Coralline Crag species not being then known from the Red, but a large number of them have since been found by Mr. P. F. Kendall, at Walton, and by myself at Little Oakley, a new and somewhat more recent zone of the Waltonian Crag. An inspection of a list of Coralline Crag species shows that with the exception of a few small or tender shells, whose absence from a beach deposit may be easily accounted for, almost all the most abundant and characteristic Mollusca of the Coralline Crag have now been found in the Waltonian, as have been also the greater part of its Polyzoa.

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[*] I noticed two powerful steam dredgers at work in an old channel of the River Maas, now nearly silted up, which raise, I was informed, 100,000 tons of dead shells per annum. Enormous quantities of shells are also collected from the Dutch beaches for lime burning.

[†] "The Influence of the Winds upon Climate during the Pleistocene Epoch," *Quart. Journ. Geol. Soc.*, vol. lvii, p. 405, 1901.

[‡] I have had many opportunities during recent years of studying the deposits of the south of Europe regarded by French and Italian geologists as Older Pliocene, and have formed a strong opinion that, even allowing for difference of latitude, they are older than any part of the East Anglian Crag.

The Walton Crag, however, contains certain species unknown from the Coralline, notably the sinistral whelk, *Trophon* (*Neptunea*) *contrarius*, and some others, as,

Nassa propinqua,
„ *elegans*,
* „ *reticosa*,
Purpura lapillus,
„ *tetragona*,
Bela turricula,
Pleurotoma coarctata,
Lacuna subaperta,
Eulimene pendula,
Eulimene terebellata,
Trochus noduliferens,
Conovulus pyramidalis,
Cardium parkinsoni,
Astarte sulcata,
* „ *obliquata*,
Pholas crispata,
„ *cylindrica*,

of these, however, those marked * are known to have been living in the North Sea in Diestien or Casterlien times.

None of these are modified descendants of Coralline Crag species, but were immigrants from some outside region, their appearance at this stage having been more or less due to the sudden opening up, by the tectonic movements before alluded to, of communication with northern seas.[†] At the somewhat later period of the Little Oakley deposit, other immigrants, including some arctic species, arrived in the Crag basin from seas still further north. Neither at the Walton nor the Oakley stage, however, had sufficient time elapsed to allow for the extinction of the greater part of the characteristic Mollusca of the Coralline Crag—that took place later—although some of these were less abundant in the Waltonian than in the Gedgravian Sea.

While, therefore, the Coralline Crag is clearly marked off from that of Walton, as a distinct zone, by the physical changes and by the additions to the fauna alluded to, it seems nearly related to it, sufficiently so, I think, to warrant our regarding the former as Newer Pliocene, the oldest member of a more or less continuous and closely connected series.

The distinction between the Lenham beds and the Coralline Crag, is of much greater importance. The former, with the other deposits referred to in an earlier part of this paper, may still be grouped as Older Pliocene. The division between the Older and the Newer Pliocene should therefore, I consider, be drawn between Lenham and the Coralline Crag, rather than between the latter and the Waltonian.

The principal exposures of the Waltonian Crag are, first, those of the cliff section at Walton, next, a small outlier at Beaumont, described 50 years ago by the late John Brown of Stainway,[‡] and last, that of Little Oakley and Ramsey, mid-way between Beaumont and Harwich (fig. 9). The fauna of a pit near Foulton Hall at Little Oakley has proved to be exceedingly rich. From a seam about 2 ft. in thickness, and 10 or 12 yards only in length, I have succeeded in obtaining more than 500 species and well-marked varieties of Mollusca, Polyzoa, &c.,* some of them new to the Crag or to science.

[†] An interesting proof that the Red Crag sea extended to the north of East Anglia is afforded by the fact that some of the characteristic fossils of that deposit, such as *Voluta lamberti*, *Nassa reticosa*, *Trophon costifer*, *Turritella incrassata*, *Astarte mutabilis*, and others, have been found in glacial gravels in Aberdeenshire, no doubt derivative from Crag beds formerly existing in the bed of the North Sea, at no great distance from the coast. *Quart. Journ. Geol. Soc.*, vol. xxxvii, p. 155, 1882.

[‡] For Brown's list of Beaumont fossils, see *Mem. Geol. Surv. Walton-Naze and Harwick*, p. 14, 1877. I have since added largely to this list.

The molluscan fauna of Beaumont is nearly, but not quite, identical with that of Walton, belonging possibly to a slightly newer stage. That of Little Oakley is decidedly more recent, although distinctly Waltonian. It contains all the characteristic and common southern and extinct Mollusca of the Walton zone, but in addition, a number of northern species which had not penetrated so far south at the Walton period.

Among these may be mentioned:

Trophon (*Neptunea*) *antiquus*, (the dextral form) not very rare,
,, *despectus*, not very rare,
,, *turtoni*,
,, *scalariformis*, common.
,, (*Sipho*) *tortuosus*, not very rare,
,, *islandicus*,
Bela scalaris,
,, *assimilis*,
,, *pyramidalis*,
Natica clausa, common,
,, *helicoides*,
Pecten islandicus,
Modiloa modiolus,
Tellina obliqua, not rare,
,, *prætenuis*, not rare.

With the exception of those marked otherwise, these species are excessively rare at Oakley. *Tellina obliqua* and *T. prætenuis* are forms not known living, but they came in, no doubt from the north with the northern shells, and became increasingly abundant with the latter in the North Sea at the later stages of the Crag.

I have given elsewhere my reasons for believing that the sinistral form of the whelk alluded to above is not a monstrous variety of the dextral shell, as generally supposed, but, as originally

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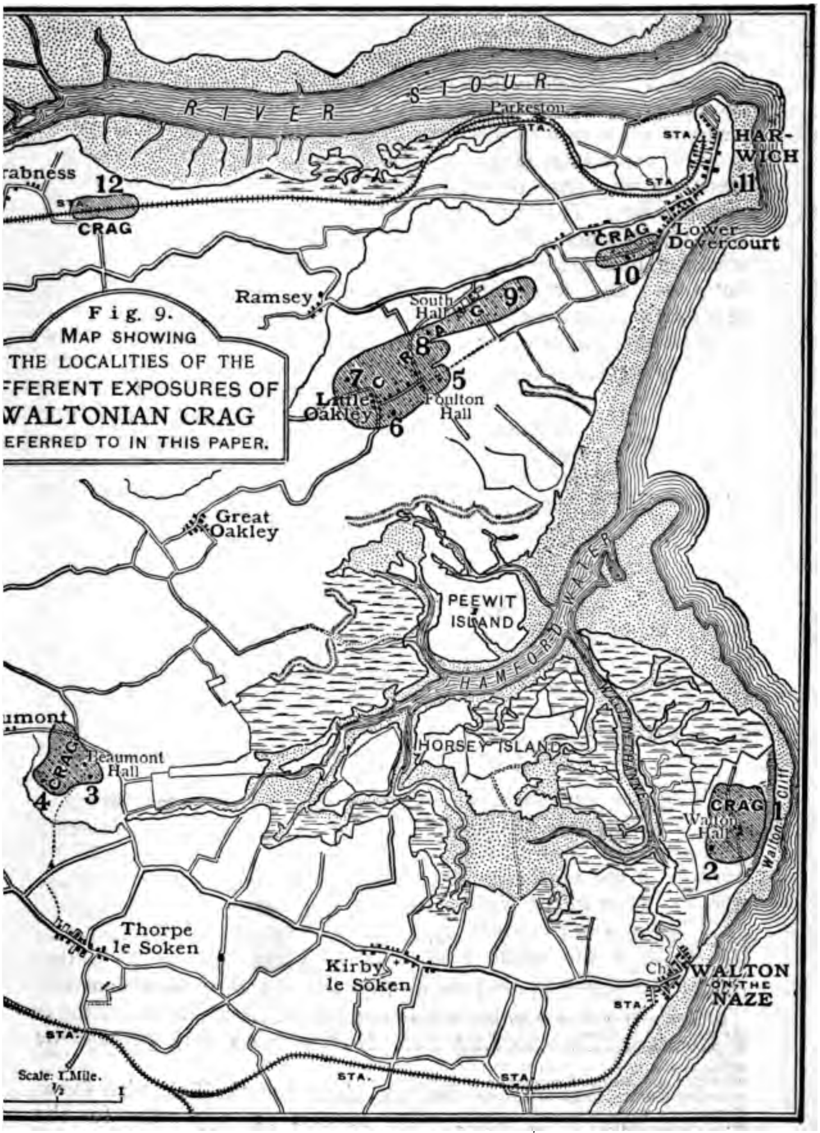
* The large number of species obtained from Oakley has been, I think, partly due to the method I employed. I used large sieves, from 12 to 18 inches in diameter, made to fit into each other for convenience of packing, fitted with long handles, with wooden sides, and bottoms of copper wire of a mesh from ¼ to 1/16 in. I employed a labourer to excavate and sift the Crag, while I examined the sifted stuff. We passed it first through a coarse sieve, and afterwards through a finer one, so as not to lose the smaller species. Sometimes, when practicable, the material was sifted dry, but more often in water, in a tub borrowed from the adjoining farmyard. The latter process not only removes the sand, but cleans the fossils at the same time. One may easily examine thoroughly in this manner from half a ton to a ton of Crag per day. It is not practicable to adopt this plan everywhere, but where the consent of the owner of the land can be obtained, I can strongly recommend it.



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described by Linnæus, a distinct species.* The two migrated southwards separately, the left-handed form arriving first in the Crag basin. *Trophon* (*Neptunea*) *contrarius* is exceedingly common in the Waltonian deposits of England, and in the Scaldisien of Belgium. A closely allied variety, *T. sinistrorsus*, penetrated as far south as the Mediterranean, being found with some other northern species in the latest Pliocene (? Pleistocene) beds of Sicily. A similar shell is now found in Vigo Bay, on the Spanish coast, but is not known further to the north. *T. contrarius* gradually became less abundant in the upper stages of the Red Crag, exceedingly rare in the Norwich Crag, and is at present unknown in British Seas.† On the contrary, the right-handed group, *T. antiquus* with its allies *T. despectus*, &c., are practically unknown at Walton and Beaumont; they appear for the first time at Oakley, and become more abundant in the later Crag beds as the left-handed shells become less so. *T. antiquus* is one of the characteristic species of the Icenian Crag, and of the various glacial deposits. It still inhabits the North Sea, but it does not range into the Mediterranean, or as far south as the coast of Spain.

The earliest stage of the Red Crag period is thus represented by the Crag of Walton Cliff. The North Sea then extended but little to the west of its present limits. The beds shown in the cliff section at Walton (fig. 7) dipping sharply to the S.S.W. must have been banked against the northern shore of a small bay which did not extend northwards into Suffolk, its southern limit lying farther south. A slight depression caused the deposition of horizontal strata upon the beach Crag and carried the Waltonian bay inland over the London clay flats, towards Beaumont. Some alteration in level afterwards enabled the sea to encroach in the direction of Little Oakley and Ramsey, at which time the northern shells had begun to arrive in increased numbers and variety.

Subsequently to this, a more important movement took place which laid dry the whole of Essex, and submerged a considerable area in Suffolk.

The region lying to the north of the Stour, together with the well-known Crag localities of Sutton, Shottisham, and Ramsholt, to the east of the latter river, is covered by Crag, the fauna of which differs in important respects from that of the Waltonian region. For this stage, I have proposed the term Newbournian. To S. V. Wood it was known as the Sutton Crag, but as Sutton is a Coralline Crag locality also, Newbournian may perhaps be preferable.

In these beds some of the most characteristic Waltonian forms are less numerous; while other species are appearing for the first time, or increasing in abundance. Of the latter may be mentioned:

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* *Proc. Inter. Congr. Zool.*, Cambridge, p. 222, 1878.

† The sinistral whelks sometimes found on our coasts are not the Crag form, *T. contrarius*, but reversed specimens of the right-handed form, *T. antiquus*.

Trophon (*Neptunea*) *antiquus*,
Cancellaria viridula,
Scalaria groenlandica,
Natica helicoides,
Modiola modiolus,
Nucula cobboldiæ,
Leda oblongoides,
Cardium angustatum,
Astarte compressa,
Tellina obliqua,
,, *prætenuis*,
Mactra ovalis,
,, *constricta*.

At a subsequent stage, the sea appears to have retired from the part of Suffolk which lies to the west of the Deben, partly perhaps because of a slight elevation of the Newbournian area, and partly because it had become choked with shelly sand, but an inlet came into existence to the west of the island of Coralline Crag of Orford and Aldeburgh. The Crag of Butley and of the Stackyard Pit at Chillesford has been generally regarded as belonging to the latest part of the Red Crag. At the stage represented by these beds a much larger number of the characteristic Walton species had disappeared, or had become rare, while the percentage of northern forms is correspondingly greater. In the Butley zone, *Trophon antiquus* is nearly as abundant as *T. contrarius*. Several species of *Leda* are not infrequent, and *Nucula cobboldiæ* is very common, while *Tellina obliqua*, *T. prætenuis*, *Mactra ovalis*, *M. constricta*, *Cardium angustatum*, with some recent British species, are so abundant as to make up a large proportion of the shells present.

There are other exposures of Crag at Alderton, Hollesley, and Bawdsey, containing a fauna similar to that of Butley, the arctic shell *Cardium groenlandicum*, almost unknown in the Newbournian deposits, being especially characteristic of the last-named locality. These, with some other exposures in the same neighbourhood, I have grouped as Butleyan, a division which contains a more recent, as well as a more boreal fauna than that of the zones before mentioned.

The distinction between the Butleyan and Newbournian zones seems to me as strongly marked as that between the other divisions of the Red Crag, or even that between the Coralline and the Waltonian. (See analysis of molluscan fauna, p. 33.)

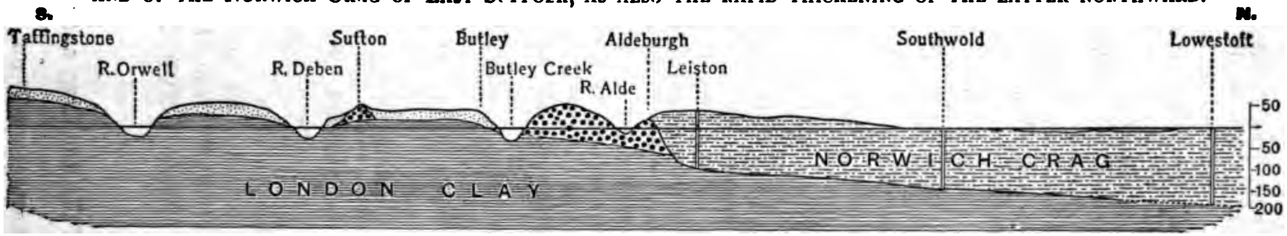
THE NORWICH, CHILLESFORD, AND WEYBOURN CRAGS.

Icenian.

These beds differ widely from those of the Red Crag, and are, I consider, considerably newer.

The latter never attain any great thickness, generally not more

FIG. 10.—SECTION FROM TATTINGSTONE TO LOWESTOFT, SHOWING THE COMPARATIVE THICKNESS OF THE RED CRAG, AND OF THE NORWICH CRAG OF EAST SUFFOLK, AS ALSO THE RAPID THICKENING OF THE LATTER NORTHWARD.



London Clay ▤ *Red Crag* ▨ *Coralline Crag* ⁘ *Norwich Crag* ▤

[The Glacial deposits are omitted.]

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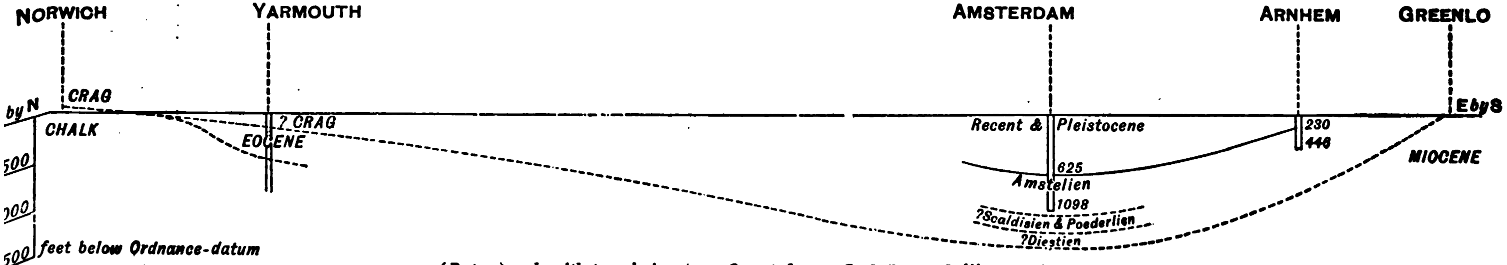
FIG. 11.—SECTION FROM NORWICH TO GREENLO.



(*Reproduced, with permission from Quart. Journ. Geol. Soc., vol. lii, p.* 753.)

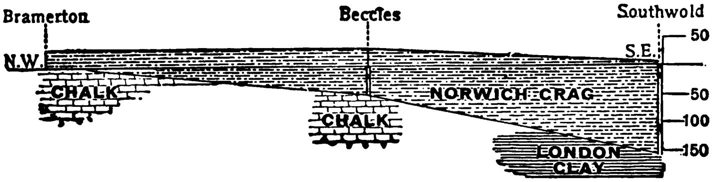
than about 20 ft., and constantly present the highly inclined bedding, as of a beach, shown in fig. 7.

The Norwich Crag on the contrary is never beach-bedded nor so uniformly fossiliferous as are the unaltered beds of the Red Crag. It occupies, moreover, a different area, coming in first immediately to the north of Aldeburgh, from which place it thickens rapidly northwards, as shown in fig. 10.

Similarly it thickens also from W. to E. (fig. 12), that is, in the direction of Amsterdam, where the Pliocene and more recent deposits are probably 1,500 ft. in thickness (fig. 11).

The conditions under which these beds originated were, I think, different to those obtaining in East Anglia during the deposition of the Red Crag. It seems not improbable that the former represent the western edge of the great delta formation of the Rhine and its affluents. In the East Anglian area occupied by the Norwich Crag, equally with that of Holland, gradual subsidence was going on, *pari passu*, with the deposition of sediment. The shells found in the boring at Southwold, for example, are throughout of the usual and shallow water Norwich Crag type.

FIG. 12.—SECTION FROM BRAMERTON, NEAR NORWICH, TO SOUTHWOLD.



[The Glacial deposits are omitted.]

(*Reproduced, with permission, from Quart. Journ. Geol. Soc., vol. lvi, p.* 734.)

The fauna of this zone is of a more recent as well as of a more northern character, the total number of species contained in it being much smaller than that of the Red Crag.

Many of the characteristic shells of the older Crag had lingered on in the North Sea, although in gradually diminishing abundance, until the Butleyan period, but nearly all of these disappeared before the Icenian stage, killed off possibly by the rapidly increasing cold.

Deposits containing the characteristic fossils of the Norwich Crag extend from Aldeburgh in Suffolk to Norwich, being found also at Horstead, Coltishall, and Burgh, in the Bure valley. The presence at some localities of a few land and fresh water shells, and of the estuarine species *Scrobicularia piperata*, has been thought to point to estuarine conditions at this period. The widespread area which these deposits cover, and their great thickness in places, seem, however, opposed to such a view (fig. 6). I am inclined to regard them as marine though accumulated near the mouth of some river, which was possibly one of the tributaries of the Rhine.

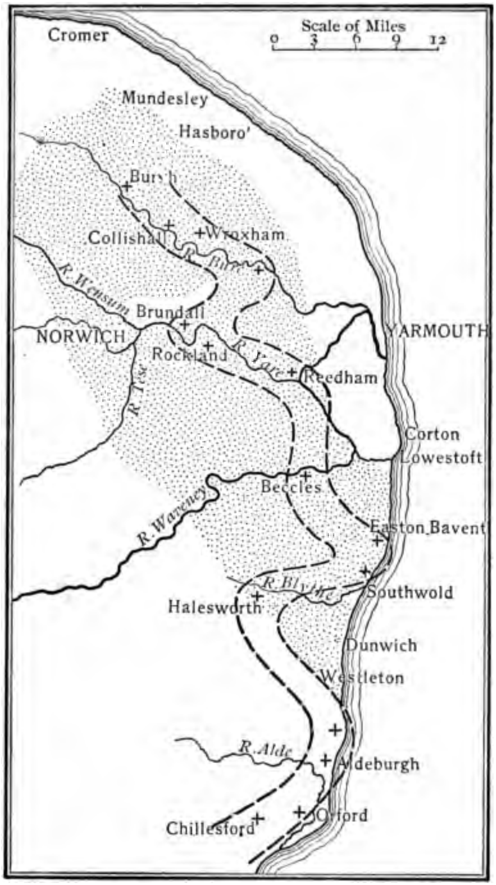


Fig. 13.—Map shewing the Principal Exposures of the Chillesford Clay (+) and the Probable Course of One of the Estuaries of the Rhine at the Chillesford Stage. (The Dotted Area indicates Approximately the Distribution of the Pebbly Gravels.)

The general character of the Norwich Crag fauna is similar throughout the whole area covered by it; the only palæontological difference by which its various exposures can be distinguished being that the arctic species *Astarte borealis* is found only in the northern part, being abundant at Norwich, and in the Bure valley, less so in the north of Suffolk, and unknown further south, as at Southwold, Dunwich, Bulchamp, and Aldeburgh. The Crag of the region characterized by the presence of this shell, one of the latest of the northern immigrants, may therefore be somewhat more recent than that from which it is absent, a view in accordance with the theory of a gradual and continued submergence towards the north. Not more than forty species of Mollusca are really common in the Norwich Crag, the most abundant being the following; about three-fourths of them are recent, and nearly two-thirds characteristic North Sea forms at the present day.

Buccinum undatum,
Purpura lapillus,
Trophon (Neptunea) antiquus,
Cerithium tricinctum,
Turritella incrassata,
„ *terebra,*
Littorina littorea,
Natica catena,
Pecten opercularis,
Nucula cobboldiæ,
Leda oblongoides,
Lucina borealis,
Cardium edule,
Astarte borealis,
„ *compressa,*
Cyprina islandica,
Tellina lata,
„ *obliqua,*
„ *prætenuis,*
Mactra ovalis,
„ *subtruncata,*
Mya arenaria,
„ *truncata.*

The Chillesford Clay is, I consider, an estuarine deposit. It may be traced through East Suffolk from Sudbourn and Aldeburgh northwards, along a somewhat sinuous line, as shown on the map (fig. 13), as far as Beccles, and thence into Norfolk to Brundall, and to Wroxham, Coltishall, and Burgh, in the Bure valley. At the two last-named places it rests upon fossiliferous sands containing the usual Norwich Crag Mollusca. Further to the north it is difficult to trace. Beds of laminated clay exist in that direction, but they may or may not belong to this horizon. The Chillesford clay seems only to retain its usual character in that part of the area where the typical deposits of the Norwich zone are present.

To the north of Burgh, the Norwich horizon of the Crag beds also disappears, with the laminated clays which can be, with more or less certainty, identified with the Chillesford zone. I have elsewhere suggested that the estuarine Chillesford Clay represents one of the channels by which the Rhine reached the sea,* as do also the estuarine gravels and clays of the somewhat later Forest-bed (so called) of the Cromer and Lowestoft coasts. The Chillesford Clay estuary, therefore, must have opened to the sea northwards. If my view of the origin of the Norwich Crag is correct, that deposit must also have formerly extended over north-east Norfolk, all traces of it in that region having been removed by subsequent denudation.

Immediately underlying the Chillesford Clay in the pit behind Chillesford Church is a fossiliferous sand containing a molluscan fauna of a somewhat different character to that which is so persistent in beds of the usual Norwich Crag type over an area forty miles in length. There is no other deposit at present exposed where precisely the same group of shells is found.† The most characteristic of these are:

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* *Quart. Journ. Geol. Soc.*, vol. lii, p. 770, 1896.

† The Crag of the Stackyard pit of Chillesford, at a considerably lower level than the Church pit, belongs, as before stated, to the Butleyan zone of the Red Crag.

Turritella terebra,
Natica catena,
Leda oblongoides,
,, *lanceolata,*
Nucula cobboldiæ,
,, *tenuis,*
Cardium edule,
,, *groenlandicum,*
Mactra ovalis,
Tellina lata,
,, *obliqua,*
Mya truncata.

Many of the bivalves occur with both valves adherent, but not specially in the position of growth. The deposit does not wholly represent an undisturbed sea-bottom; most of the shells appear to have been drifted, and may have been brought up by the scour of the estuarine tides, having been buried while living, or soon after death, in the tidal sediment.*

The fossils of the Chillesford Church pit are in a decayed condition, resembling those found in freshwater strata, and contrast strangely with the better preserved shells of the marine Crag.† Mr. J. Lomas states that, when examined under the microscope, the grains of the sand in which these fossils occur are seen to be less rounded than those of the beach sands of the Red Crag.‡

The Chillesford Clay is specially characterized by the constant presence of minute flakes of mica, derived, it may be, from the Devonian Schists of the Ardennes, or possibly, as suggested by the Cav. W. P. Jervis, from micaceous rocks further to the south.§ Mica is also common in many of the Dutch deposits.

This stage of the Pliocene history was thus marked by a slight elevation, by means of which East Anglia became land, traversed by an arm of the Rhine, the German Ocean having retired somewhat further to the north.

During the Weybourne stage of the Icenian period, however, the Crag Sea again encroached upon the north-eastern corner of Norfolk, penetrating, perhaps, as far south as Norwich. The molluscan fauna of this zone is the poorest, as well as the most recent, of the Crag beds. It comprises not more than 50 species altogether, almost all being common British or northern forms, and is specially characterised by the first appearance and great abundance of *Tellina balthica*, a shell never found at any earlier horizon of the Crag. The sudden appearance of this mollusc at this horizon in such extraordinary profusion, suggests that communication was at that time opened up between the Crag Sea and some area, perhaps the southern part of the Baltic, where it had previously established itself. The *Tellina balthica* Crag is met with at Weybourne and other places on the coast. Beds with a similar fauna occur also inland, as near as Aylsham, and at Belaugh, Wroxham, Crostwick, and elsewhere in the Bure valley. The occurrence of this species is not recorded at any place to the south of Norwich.

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* The Rev. O. Fisher, however, describes a bed of *Mya truncata* in the position of growth at the base of the Chillesford section, which is not now visible.

† There is a similar difference in the condition of the shells dredged in Strangford Lough, an extensive sheet of water communicating with the Irish Sea by an exceedingly narrow channel, and of those met with in the open sea outside.—*Rep. Brit. Assn., Dublin*, p. 110, 1857.

‡ *Quart. Jour. Geol Soc.*, vol. lvi, p. 724, 1900.

§ *Trans. Vict. Inst.*, vol. xxxii, p. 327, 1898-9.

The mutual relationship of the various horizons of the Crag may be summarized as follows:

ANALYSIS OF THE MOLLUSCAN FAUNA OF THE DIFFERENT HORIZONS OF THE CRAG. (CHARACTERISTIC AND ABUNDANT SPECIES ONLY.)

	Not known living. per cent.	*Living only in distant seas.* per cent.	*Southern.* per cent.	*Northern.* per cent.	*Northern and Southern.* per cent.
edgravian	38	4	26	1	31
Waltonian	36	4	20	5	35
Newbournian	32	5	16	11	36
Butleyan	13	4	13	23	47
Icenian	11	—	7	32	50
Weybournian*	11	—	—	33	56

In calculating the various percentages, the more characteristic species of each zone only are taken into account. It is not always easy to draw the line between rare and abundant forms, and possibly the details which might be tabulated by another observer would be somewhat different. I have little doubt however that, in any case, the general results would agree with those here given, and that the foregoing statistics, though they must be regarded as approximate only, justify the conclusions to be drawn from them.

THE FOREST-BED SERIES.

Cromerian.†

Again the sea retired, and East Anglia became land, as during the Chillesfordian stage, but the estuary of the Rhine lay somewhat further to the east.

Up to this period the fossils of the Pliocene deposits of the East of England indicate a uniform and continuous refrigeration in the climate of that region.

The fauna and flora of the Forest-bed series, on the contrary, seem to point in another direction, presenting the first of those climatal oscillations which, in the opinion of many geologists, were characteristic of the glacial and post-glacial epochs.

The Forest-bed and its fauna were once supposed to indicate the site and the animal life of a former East Anglian woodland. The tree-stumps, so frequently met with in that deposit, however, do not occur in place, but have been drifted; the mammalian remains are not found as perfect skeletons, but as isolated and often fragmentary bones or teeth, and may represent the fauna of some part of the Rhine valley towards the south, rather than that of East Anglia. A possible explanation of the presence of these fossils in such abundance in the Forest-bed may be that animals browsing in herds on the low grounds bordering the river were overtaken from time to time by sudden and violent floods and swept by the current down to their present resting place.

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* The above figures do not adequately represent the modern character of the Weybournian fauna. If individuals could be counted rather than species, the recent shells would form more than nine-tenths of the whole; the specimens of *Tellina balthica* alone far outnumbering all the others put together.

† This is the name adopted by Renevier, *Chronogr. géol.*, 2nd edit., 1896. "Tableau des Terrains sédimentaires."

During the period represented by the estuarine deposits of the Forest-bed the Rhine seems to have swung round in a great bend from Kessingland to Cromer, following, more or less, the present trend of the coast. It is on the convex banks of a stream, as the river yachtsmen of Norfolk know, that shoals and mud banks accumulate. In such a position was the sediment of the great river deposited, and its wreckage stranded. In this way, I suggest, we may most reasonably explain the great abundance in one small area of tree-stumps, as well as of the bones and teeth of elephants and other animals.

The general character of the mammalian fauna is distinctly southern. A few specimens of northern forms, such as *Ovibos*, and *Gulo* have been found; those of *Elephas meridionalis*, the most characteristic of the Forest-bed mammals, are, on the contrary, exceedingly common. This, taken with the fact, stated by Mr. Reid, that the flora of these deposits is similar to that of East Anglia at the present day, indicates, I think, that the climate of north-western Europe at this period was not severe.

Associated with the estuarine gravels and clays of the Forest-bed are some fresh water deposits, implying slight changes in the position of the Rhine, and probably in the level of the land. As the river shifted its course eastwards, the mud flats of its estuary became the site of swamp, morass, or shallow lake, presenting conditions more or less similar to those of the Broadland of the present day.

A bird's-eye view of Norfolk at this period would have been one of low sandy plains covered by woods of spruce or Scotch fir, with groves of beech, oak, or elm, in places, and a tangled undergrowth of bramble, hawthorn, and hazel. On the west, rolling chalk downs; on the east, broads and swamps, filled with aquatic plants such as now grow in the district, and fringed with thickets of alder, willow, and birch. Further to the east lay the great estuary, often swollen and turbid and then sweeping down, with other flotsam and jetsam, the stools of trees, torn from its undermined banks, and, from time to time, the carcases of elephant or deer. Beyond the Rhine, on the opposite shore, a vast plain, now covered by the sea, but then dark with pine forests, stretched eastward to the distant horizon, and thence to Holland.

The plant and animal life of East Anglia at this period was varied and abundant. The Broads and streams, which as at present swarmed with fish—pike, roach, perch and bream—were margined with the water lily, and the water plantain, and with masses of dock, sedge and reed. The marshes were gay with meadow rue and cotton grass, and with buttercups and the golden flowers of the *Caltha*, while here and there arose a great clump of the royal *Osmunda*. Flocks of geese and wild duck, undisturbed by tourist or sportsman, made their home in these inland waters, and in the evening the owl, on noiseless wing, scoured the country in search of its prey. Squirrels chattered in the trees, and frogs croaked in the damp meadows, dotted then as they are to-day, by the rounded hillocks of the mole. From their holes in the river banks, or their lairs in the reed beds, otters issued for their nightly fishing, while beavers were busy in the construction of their dams. Smaller animals, as mice, shrews, and water voles, everywhere abounded, and the poisonous adder lurked in the woods.*

Such was then the aspect of the Pliocene Broadland, presenting, more or less, the features which were in after times to make it famous; but once more the scene changed.

The climate of the northern hemisphere again became colder, and the Great Ice age was soon to hold East Anglia in its wintry grasp. An indication of its approach is afforded by the *Leda myalis* sands, and the arctic freshwater bed of Mundesley and Beeston, the latter containing the northern plants, *Salix polaris*, *Betula nana*, and *Hypnum turgescens*, and grouped by Mr. Reid with the glacial deposits. No important break seems to exist in East Anglia, however, between the Pliocene and the Pleistocene, and otherwise than locally no satisfactory line can be drawn to separate them. Glacial conditions had probably commenced in Scandinavia during the deposition of the later beds of the English Crag.

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* Our knowledge of the flora of the Forest-bed deposits is largely due to Mr. Reid.

PART II.

THE PLEISTOCENE AND RECENT PERIODS.

Although the Glacial deposits of East Anglia have been closely studied for many years, especially by the officers of H.M. Geological Survey, and more or less agreement has been arrived at as to their succession and relation to each other, there is, at the present, no consensus of opinion as to the conditions under which they originated. The subject must sooner or later be dealt with on a larger scale than is at present possible; the East Anglian deposits being considered in connection with those of other parts of Great Britain, and of the Continent (especially of Belgium), as well as with the gravels, &c., lying outside the regions actually glaciated, some of which may have been due to torrents issuing from the ice during summer at the period of maximum glaciation.

In a map of the Crag and Drift Beds of south-east Suffolk, published in 1864, S. V. Wood, Jr., first showed the relation of the Chalky Boulder Clay (which he called "the upper or clay drift") to the great sheet of sand and gravel ("lower drift") which underlies it in that region.* During a visit to Norfolk, in the summer of the same year, he ascertained that the Glacial deposits of the Cromer coast belonged to a still older horizon, and in a second map, and a paper printed for private circulation, copies of which he placed in the Library of the Geological Society, he adopted a tripartite division of the Glacial beds.† Such a classification may be of local application only, but, as to East Anglia, the succession proposed by Wood has been more or less generally followed.

The most important development of the deposits called by Wood "Lower Glacial," is to be found in the north-eastern part of Norfolk. The well-known coast section, extending from Hasboro' to Weybourne, has been much studied by geologists (perhaps to the comparative neglect of other parts), and specially by Mr. Clement Reid, whose views on the subject were stated in 1880, in an important paper,‡ and afterwards in his Survey Memoir.§

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* *Ann. Mag. Nat. Hist.*, Ser. 3, vol. xiii, pl. xvii.

† "Remarks in explanation of a Map of the Upper Tertiaries of Norfolk, Suffolk, &c." 1865.

‡ *Geol. Mag.*, Ser. 2, vol. vii, p. 55, 1880.

§ *Mem. Geol. Survey*, Cromer, 1882.

THE LOWER GLACIAL DEPOSITS OF EAST ANGLIA.

(a) **The Cromer Till, and the Pebbly Series (Westleton Shingle).**

The Cromer Till may be conveniently studied at the south-eastern extremity of the Norfolk coast section, near Hasboro', where it rests on the Pliocene beds, and is exposed at the base of the cliff. It consists there of a dirty looking blue clay, rather sandy, hardened, and sometimes pseudo-bedded, apparently by the pressure of ice moving over it. It contains many recent shells, more or less broken, especially *Tellina balthica*, *Cardium edule*, and *Cyprina islandica*, with grey flints, and small striated boulders of hard chalk. Mr. Reid has noted also the presence of red chalk, Kimeridge clay, Lias, New Red sandstone (?), Carboniferous sandstone and chert, and Old Red sandstone, together with igneous rocks—granite, gneiss, and basalt.* The general character of the Till and of its included débris differs, however, in important particulars from that of the Chalky Boulder Clay, the Upper Glacial of Wood. Near Mundesley, the former contains occasionally seams of sand or fine gravel.

Resting on the Till at Hasboro' are some laminated clays and sands, occasionally finely rippled-marked, as if by gently running water. An examination of these by Mr. Reid failed to detect the presence of Entomostraca, or Foraminifera, leading him to the conclusion that they were not of marine origin.

Towards Mundesley, these deposits seem to pass into the stratified sands which in that direction underlie the Contorted Drift; they may represent a temporary or local retreat of the ice foot, during which muddy streams issued from it.

Overlying the laminated beds is a deposit of chalky clay of a somewhat similar character to that of Weybourne and Wells (see p. 39), which Mr. Reid describes as a "Second Till," but which Wood regarded as Contorted Drift. Its included boulders are similar to those of the basement Till, but it contains much soft upper Chalk débris, probably derived from a source nearer at hand than that of the hard Chalk of the latter. As we trace the Glacial Beds westwards towards Mundesley, this upper boulder clay appears to pass into the Contorted Drift, which has been in places in that direction much disturbed, more or less contemporaneously, I think, with its deposition; the sands overlying it (probably Middle Glacial) showing there no similar evidence of disturbance.

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* *Mem. Geol. Surv.*, Cromer, p. 87. 1882.

Both the Till and the Upper Boulder Clay may have been due to ice originating partly on the Chalk to the north-west, but the shelly débris they contain indicates that in approaching Norfolk it also travelled, for a part of its course, over the sea bottom.

In order to explain the greater abundance of soft chalk in the Upper Clay, Mr. Reid suggests that the ice, during its first advance, ploughed off many of the shelly sand-banks then resting on the sea bottom, passing during its second advance over bare chalk.[*]

He remarks, moreover, that some of the included boulders have been bored by annelids, and subsequently striated, pointing to the agency of coast ice for their original introduction into the East Anglian area. In this way, some of the small boulders of rhomb-porphyry which are from time to time picked up on the beach, no doubt derived from the cliff, may also have reached us.

By far the larger part of the débris contained in the Lower Glacial Clays is of Cretaceous origin. Of the pebbles now lying on the beach, derived from the destruction of the cliffs in past times, more than 95 per cent. are flint.

Underlying the Norwich Brickearth (to be dealt with later on) to the north of that city, as at Hellesdon, Sprowston, and elsewhere, are some unfossiliferous pebbly gravels, composed almost entirely of flint, sometimes interstratified with sand, which were correlated, but I now think erroneously, by Wood and myself in 1868, with the *Tellina balthica* Crag of Weybourne and Belaugh.[†] It appeared to me, when mapping the country during the years 1865-1870, that these pebbly gravels might be traced in a south-easterly direction, to Halesworth and Southwold, and thence to Westleton and Dunwich, as shown on the map (fig. 13). Messrs. Whitaker and Dalton, without committing themselves to the Glacial age of these beds, have recognised them as occupying a definite position between the Chillesford Clay and the Glacial deposits,[‡] and a similar view was taken by the late Mr. J. H. Blake.[§] Mr. H. B. Woodward, however, considers the pebbly gravels of Hellesdon, &c., to be of Crag age, while, with Prestwich, he regards the shingle of Westleton as "Middle Glacial."[||] It is undoubtedly true, as Mr. Woodward points out, that seams of pebbly gravel occur occasionally, both in the Crag and in the Middle Glacial Sands; similarly, we sometimes find on our coasts at the present day that the beach is covered with shingle at one spot, and at another, a mile further on, with sand only. The Pebbly Gravels maintain a persistent character, however, over so large an area, that I still believe, with the geologists just named, that they indicate a distinct horizon, and that they originated under special conditions. The Middle Glacial Sands, although they sometimes contain seams of flint pebbles (possibly in places reconstructed Westleton Shingle), and are largely composed of gravel towards the south, maintain in the region in question their prevalently sandy character. The Pebble Beds, composed almost entirely of flint, suggest much contemporaneous denudation of the Chalk. They may represent the littoral deposits of a shallow sea of Lower Glacial age, or, possibly, the product of a sub-glacial stream issuing from the chalk country to the north-west, a region that was afterwards to furnish material for the chalky clays by which at a later stage of its history East Anglia was covered.*

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[*] *Loc. cit.*, p. 91.

[†] *Rep. Brit. Assoc.*, Norwich, p. 83, 1868.

[‡] *Mem. Geol. Survey*, Halesworth, p. 11, 1887.

[§] *Mem. Geol Survey*, Yarmouth, p. 25, 1890.

[||] *Geol. Mag.*, December 4, vol. ix., p. 27, 1902.

(b) The Contorted Drift, and the Norwich Brickearth.

The area continuously covered by the beds, newer than the Pebbly Gravels, grouped by Wood and myself as Lower Glacial, is situated to the north-east of a line drawn in a south-easterly direction from the eastern limit of sheet 69 (fig. 15) to Corton (between Hopton and Pakefield) on the coast. From sheet 69 to the south-eastern corner of 68 S.W., this line roughly divides the area occupied by the Lower Glacial clays, left white on the map, and that of the Chalky Boulder Clay, coloured black, but towards the east, in sheets 66 N.E., and 67, the latter overlaps and overlies the former. The superposition of the one to the other may be there seen in vertical section, as in the cliff at Corton and elsewhere.

Immediately to the north, north-east, and north-west of Norwich, the Lower Glacial deposits are represented, first, as I think, by the pebbly flint gravels already mentioned, and next, by a bed of sandy brickearth, of a dark reddish brown colour, which from the time of the Romans to the present day has been drawn on for building purposes. This seam of brickearth, attaining a thickness of ten feet and upwards in the neighbourhood of that city, thickens out northwards, being overlain in that direction on higher ground by yellow sands (Middle Glacial). Traced eastwards in the direction of Yarmouth, and northwards towards Cromer, Mundesley, or Hasboro', the Norwich Brickearth passes horizontally into the Contorted Drift of the coast.

Towards the north-west, in the direction of Holt and Wells, the Lower Glacial clay consists of an impervious marl, so chalky that it is generally burned for lime in preference to the Chalk itself. This marly condition of the Contorted Drift is well shown in a large excavation near the railway station at Wells. Passing eastwards from Wells, we find the Lower Glacial maintaining a similar character at Weybourne, but as we follow the cliff section towards Cromer, it gradually assumes the contorted condition to which its appropriate name is due. Enormous masses of marl, similar in character to that of Weybourne and Wells, and of marly chalk, sometimes showing lines of flint *in situ*, are associated with beds of clay, loam, sand, and gravel, the stratification of which has been, over a certain district, constantly disturbed and bent.

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* As one approaches Marseilles by train from Tarascon and Arles, the country is seen to be overspread by a great sheet of gravel (the *campus lapideus* of the Romans, and the supposed scene of the combat between Hercules and the Ligurians), the detritus brought down by the Rhone in Glacial times, which reminds one strongly of the Pebbly Gravels of East Anglia.

The included masses of chalk and marl, and the contortions of the stratified drift tend generally to disappear, however, as we trace the Lower Glacial deposits to the south-east of Cromer. Messrs. H. B. Woodward and C. Reid consider that the contortions were not contemporaneous, but that they were caused at a later stage by the ice to which the Chalky Boulder Clay was due, that ice having then reached the Norfolk area from the north-east. The disturbance of the Contorted Drift was no doubt due to the North Sea ice, but partly, I think, at the time of its deposition; partly, possibly, contemporaneously with the maximum extension of the Chalky Boulder Clay glacier; the latter, however, approached East Anglia, as I shall endeavour to explain later on, from the north-west,* and did not ever reach the Cromer coast.

The Lower Glacial Brickearth (the Contorted Drift in its uncontorted form) may be traced continuously from Norwich over the region lying to the north-east of the River Yare, and thence, as just stated, into Sheet 67 (fig. 15). The mapping of that sheet presents no difficulty, the three divisions of the Norfolk drift, the Lower Glacial Brickearth, the Middle Glacial Sands, and the Chalky Boulder Clay occurring in regular succession (fig. 14). To the south of Norwich, exposures of the Lower Glacial Brickearth become intermittent. Further to the south, in Suffolk, beds of sandy clay and brickearth occur in places, which seem to be of Lower Glacial age. Wood held strongly to the opinion that the Lower Glacial clays formerly extended over the eastern part of Suffolk, and that, although much denuded at a later stage, masses of them may still exist, concealed under the Chalky Boulder Clay of that region.

The Contorted Drift of the Cromer coast, equally with the Norwich Brickearth, occasionally contains crystalline erratics of moderate size, rarely to be observed, however, *in situ*, but here and there, lying on the beach, or inland near farmhouses, or as *rejectamenta* in brick-pits. Swedish geologists have expressed the opinion that some of them may be of Scandinavian origin. As a rule, they are not of a sufficiently distinctive character to enable the petrologists to whom I have submitted my specimens to express any decided opinion as to their origin.[*] The basaltic boulders frequently met with are possibly British, or may have come from the Rhine. Mr. Kendall informs me, on the authority of Professor Brögger, that there is no large area covered by such rocks in Scandinavia.

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* Mr. H. B. Woodward has expressed a similar view. *Proc. Geol. Assoc.*, vol. ix, p. 125, 1885.

In a deep railway cutting near Utrecht, on the contrary, which I visited with Dr. Lorié, I noticed, in sandy beds of a similarly contorted character to those of Norfolk, an enormous number of large granitic and other crystalline boulders clearly recognisable as Scandinavian.[†] These morainic deposits are believed by Dr. Lorié to represent the southern limit of the Baltic ice-stream.[‡] They show a much closer, and a different kind of relation to it than that of the drifts of the Cromer coast. Scandinavian erratics have, however, been noticed in the boulder clays of Yorkshire and Lincolnshire. On the other hand, the masses of chalk in the Contorted Drift, often in a marly condition, as if they had been subjected to the pressure of ice moving over them, seem to me to establish a close connection between the Norfolk deposits and some Chalk strata land, then existing to the northward, from which they may have been brought. The character of the Contorted Drift itself, becoming more marly as we trace it towards the north-west, points in the same direction.

I suggest, as a working hypothesis, that all these beds—the pebbly gravel, the Cromer Till, and the Contorted Drift, as well as the disturbance of the latter, and the introduction of the marl masses, may have been due to an ice stream, fed by the snows of the Yorkshire Hills, which travelled towards the lower ground of Eastern Norfolk along the eastern side of the Wolds, in the same direction as that of the lower part of the estuary of the Humber, being possibly pressed against the Wolds by the Scandinavian ice.

As the ice began to travel in a south-easterly direction, but before it had reached the Cromer coast, streams might have issued from the ice foot, bringing over the eastern portion of Norfolk and Suffolk quantities of flint pebbles.[§] The uniformly fine and rounded character of these pebbles, differing widely from that of the other glacial gravels of East Anglia, shows, I think, that they must have travelled some distance.

The Hasboro' Till seems also to have come from the north or north-west; there is no trace of the existence of any bed of the same character inland; moreover, the presence in it, as in the Contorted Drift, of fragments of marine shells, shows that the ice to which it was due approached Norfolk from the sea.

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[*] Pebbles of Scandinavian rocks are sometimes met with on the beach, but these do not necessarily prove that the Scandinavian ice-sheet reached East Anglia.

[†] See also Lorié, *Contr. a la Géol. des Pays Bas.* part 2, Arch. Tayler, 1887.

[‡] See map, pl. xxxiv, *Quart. Journ. Geol. Soc.*, vol. lii, p. 782, 1896.

[§] The occasional presence of red flint (supposed by Mr. Reid to be of Danish origin, *Mem. Geol. Surv.*, *Holderness*, p. 18, 1885) in the Pebbly gravels, as in the basement clay of Bridlington shows, however, that some connection between the East of England and the Scandinavian ice had, by this time, been established.

The Contorted Drift differs essentially from the Chalky Boulder Clay, not only in the character of its included erratics, but also, in what is of greater importance, in the material of which it consists. As has been long known, the larger boulders in the Lower Glacial are mainly those of igneous rocks. In the Upper Glacial the latter are rare, but, as all observers have recognised, débris from Secondary strata, seldom in the form of large blocks, is exceedingly common. The chalky Boulder Clay is always, as its name denotes, of a more or less stiff and clayey nature, and forms wet, heavy, wheat-growing land, as, for example, that of middle and south Norfolk and Essex. Not only does it contain abundantly in the region mentioned, fragments and boulders of Jurassic as well as of Cretaceous rocks, but its matrix is often of a dark blue colour, having evidently been derived from Secondary clays. On the other hand, the Contorted Drift, where it is not marly, assumes the character of a sandy brickearth, with associated beds of sand and gravel, and the district it covers is regarded locally as "good mixed soil," and never as "strong clay land." As the Chalk highlands are approached, however, the Upper and Lower Glacial deposits resemble each other more nearly; the matrix of the latter being very chalky in north-west Norfolk, and that of the former, where it rests on the Chalk, as near Hitchin or in Lincolnshire, where it hugs the western and southern parts of the Wolds, decidedly so.[*] In spite of this exception, not in any way antagonistic to the views expressed in this paper, the marked difference in the character of the two deposits over the greater part of the district, as well as that of their included boulders, indicates that the ice streams to which they were severally due, while originating on or against the Chalk highlands, must have crossed in their journey to East Anglia a different series of rocks, and have followed different routes.

The latter point seems further indicated by the fact that, while shell fragments frequently occur in the Lower Glacial Clays of East Anglia, they are not found in the Chalky Boulder Clay of that region.

Although the Lower Glacial beds may sometimes represent the *moraine profonde* of moving ice, as is probably the case towards the west, where they assume their marly condition, they have often, when they consist of brickearth, the appearance of an aqueous deposit originating in a closed basin from which tidal currents were excluded, in which fine mud could quietly settle. When the North Sea was blocked by the Scandinavian ice, such a closed basin might have existed to the south of the ice foot, a great glacier-lake in fact, in which the drainage of the continental rivers flowing northwards accumulated. In this way, I suggest, some of the Lower Glacial brickearths, which closely resemble the recent alluvium of the Rhine and the Meuse, may have originated. It would be interesting to ascertain the result of a more accurate comparison of the latter deposits with our own.*

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[*] As Mr. H. B. Woodward points out, it is not easy in west Norfolk to distinguish between the marly clay of Wells and Fakenham, and the Chalky Boulder Clay of the district to the south of the latter town. In a geological map recently published by him ("Victoria History of the County of Norfolk", 1901) following the lithological method of mapping the East Anglian drift beds adopted by the Survey, he uses the same colour for the two deposits, but he agrees with me in believing the former to be of Lower and the latter of Upper Glacial age.

The volume of water brought down by these rivers during the Glacial period must have been far greater than that of our own times. Not only would the melting of the ice covering the Alpine region produce violent floods during the summer, but generally the rainfall of Western Europe may have been then more copious. The existence of permanent ice, and of arctic conditions so far to the south, and over a region the winters of which are now abnormally mild, must have produced much meteorological disturbance, and increased precipitation. The post-glacial "pluvial epoch," which has often been insisted on, may have commenced in glacial times.

THE MIDDLE GLACIAL SANDS OF EAST ANGLIA.

This formation, which occupies, more or less continuously, a large area in the eastern part of the counties of Suffolk and Norfolk, attaining a maximum thickness of 60 or 70 feet,† indicates an important and clearly defined stage in the glacial history of the district.

In the south-eastern corner of Suffolk, from the Stour to the Alde, the area lying to the south-east of a line joining Ipswich, Woodbridge, and Aldeburgh (that of the Red Crag), it forms a succession of sandy heaths on the higher land intervening between the valleys by which that region is intersected, the underlying Crag being exposed only along the sides of the valleys.‡ In places, the Middle Glacial Sands have denuded the Crag, as at Wilford Bridge, near Woodbridge.

To the north and north-west of the Red Crag area, these sands pass under the great sheet of Chalky Boulder Clay which covers the higher part of Suffolk and south Norfolk; in that district the sand comes to the surface in the valleys only, where erosion has cut through the Boulder Clay to a sufficient depth. Along a narrow strip of country in east Suffolk, however, extending from Aldeburgh to Yarmouth, the Middle Glacial is more largely exposed, as the Boulder Clay only reaches the coast at a few points.

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* The microscopical and analytical study of the constituents of the glacial clays of East Anglia is likely to give more interesting results than that of the stones or the boulders they contain. It ought to be possible in this way, I think, to ascertain with absolute certainty the paths of the ice streams.

† It was proved to be 69 ft. thick at East Dereham (*Mem. Geol. Survey*, Dereham, p. 55) and it exceeds 50 ft. at Wilford Bridge.

‡ A reference is suggested to a sketch map of this district in *Quart. Journ. Geol. Soc.*, vol. lii, pl. xxxv, and to Mr. H. B. Woodward's map of Norfolk (see footnote on last page).

Beyond Norwich, the Lower Glacial brickearths are overlain by sands of a similar character, which form extensive heaths of very light land to the north of that city; that these sands occupy generally the same geological horizon, though possibly they may not be absolutely synchronous, with those of Suffolk, is shewn by the fact that the former, when traced eastwards towards Yarmouth, pass under the Chalky Boulder Clay, while the latter, followed northwards in the same direction, pass over the Lower Glacial Brickearth.

To the south of the Red Crag area the Middle Glacial beds become, as before stated, gravelly, and occasionally, as near Lowestoft, they contain pebbles, possibly derived there at second hand from the Westleton beds. Their general character over the large area just described is, however, that of rather coarse-grained sand, often current-bedded, with occasional seams of small subangular fragments of flint, or small, rounded pellets of chalk. Where protected by an overlying covering of boulder clay, the sand is sometimes largely composed of chalk grains, which were found in one case to form more than 30 per cent. of the whole.[*] Where the Middle Glacial comes to the surface, and is unprotected by clay, the chalk grains have been removed by the infiltration of acidulated water, and the sands have been stained a bright yellow colour by peroxide of iron.

In the year 1868, when mapping the district known as the Flegg Hundred (fig. 14), to the north-east of Yarmouth, I came accidentally on a rich fossiliferous seam in the Middle Glacial Sands at Billockby and Clippesby, villages about seven miles north-east of that town, which had been protected from decalcification by the Chalky Boulder Clay immediately overlying it.

Fossils were afterwards discovered at the same horizon at Lound, five miles to the south of Yarmouth, and at various places in the cliff section.[†] Wood, sifting with the most indefatigable industry some tons of the material, obtained from these sands a very interesting and important fauna of more than 100 species of Mollusca, the general facies of which was of a glacial and comparatively recent character,[‡] including forms like *Tellina balthica*, *T. crassa*, *T. obliqua*, *Scrobicularia piperata*, *Mactra ovalis*, *Corbula striata*, *Mya arenaria*, *M. truncata*, *Pholas crispata*, *Cyprina*

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[*] In the report of an analysis of some Middle Glacial Sand made for me many years ago by Mr. Fras. Sutton, F.C.S. (*Geol. Mag.*, vol. iii, p. 43), the percentage of carbonate of lime was stated by a printer's error to be 3¼ It should have been 31·2.

[†] John Gunn, the Rector of Irstead, had found marine shells in the Middle Glacial Sands of Caister, near Yarmouth, as far back as 1836. See also C. B. Rose, *Proc. Geol. Assoc.*, vol. i, p. 192, 1861.

[‡] The Ostracoda of the Middle Glacial Sands are generally of an arctic character. Brady, Crosskey, and Robertson, *Pal. Soc.*, 1874, p. 103.

islandica, *Cardium edule*, *Nucula cobboldiæ*, *Mytilus edulis*, *Pecten varius*, *P. opercularis*, *Anomia ephippium*, *Trochus cinerarius*, *Natica catena*, *N. alderi*, *Littorina littorea*, *Turritella terebra*, *Trophon (Neptunea) antiquus*, *Purpura lapillus*, *Buccinum undatum*, and *Nassa incrassata*. Among the northern forms found may be mentioned, *Panopæa norvegica*, *Tellina lata*, *Astarte borealis*, *A. compressa*, *A. sulcata*, *Leda oblongoides*, *L. lanceolata*, *Natica clausa*, *N. helicoides*, *Scalaria groenlandica*, *Bela turricula*, and *Trophon scalariformis*. Under ordinary conditions these shells would have been regarded, without hesitation, as the contemporary fauna of the Glacial deposit in which they occur, but Wood found also with them a few specimens of southern and extinct species which had been common in the North Sea during

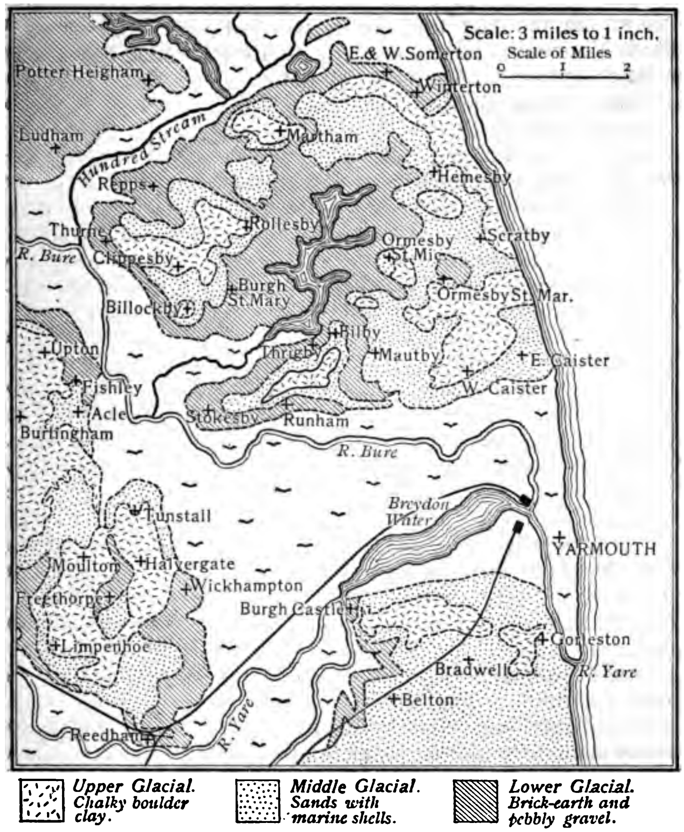

FIG. 14.—THE FLEGG HUNDRED.

earlier and middle Crag times, but, as far as we know, had died out in that region before the Glacial period. Among these were *Cytherea rudis*, *Woodia digitaria*, *Astarte burtinii*, *A. omalii*, *Erycinella ovalis*, *Cardita scalaris*, *C. corbis*, *Leda pygmæa*, *Dentalium dentalis*, *Calyptræa chinensis*, *Turritella incrassata*, and *Trophon muricatus*. To explain the anomaly of the presence of such shells in a glacial deposit, the hypothesis was suggested that they had been derived from some older Crag beds, but this view, for which no evidence has been offered, I am entirely unable to accept. There is no reason to suppose that while most of the specimens are proper to the deposit, others are derivative; they are all in the same mineral condition, and no distinction can be drawn between them.

Many are exceedingly fragile, as for example, young shells of *Anomia ephippium*, from ⅛ inch in diameter, which are very common, and almost as thin as tissue paper. Most are small, such as might have been brought into the area by tidal currents. Although some are fragmentary and broken, others are as perfect as the shells of the Coralline Crag, a deposit the fossils of which were accumulated, I believe, in a somewhat similar way.

It is not the more distinctive large and strong species of the Coralline or Red Crags, whose presence might have been expected on the derivative hypothesis, as, for instance, *Trophon* (*Neptunea*) *contrarius*, so abundant in every part of the latter, that we commonly find in these beds. On the contrary, in the Glacial deposit in Aberdeenshire, already alluded to, containing derivative Crag shells, no small or fragile species were met with, the specimens being all of a more or less solid character.* Moreover, it any older Crag deposits had then existed in the Yarmouth area,† they would have been covered by a considerable thickness of Lower and Middle Glacial deposits, since it was from the highest part of the latter that the shells were obtained. If further argument were needed in opposition to the derivative theory, it would be supplied, I think, by the inspection of the specimens themselves, preserved in the Castle Museum at Norwich.

If the view here taken is correct, it follows that the connection between the North Sea and the English Channel which, I believe, existed during the deposition of the Lenham and Coralline Crags, but was interrupted at the commencement of the Red Crag period, was re-opened in Middle Glacial times.‡ That an alteration took place at this stage, both in the physical conditions of the area and the character of the sediment, is obvious. The deposition of brickearth, composed of fine material, tranquilly deposited, or of glacial clays, suddenly gave place to that of rather coarse, stratified, and false-bedded sands, due to current action. A possible explanation suggests itself. The result of the blocking of the North Sea by the Scandinavian ice must have been that the level of the extra-glacial lake so formed would be gradually raised by the continued accumulation of the water brought into it by the Rhine and its affluents, then flowing, as before urged, in greater volume than at present. Eventually, however, these waters might have forced for themselves an outlet towards the south-west, permitting the tidal currents of the English Channel again to find their way into the German Ocean, bringing, as during the deposition of the Coralline Crag, the Mollusca of southern seas.

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* The Aberdeenshire specimens were submitted to S. V. Wood, Senr. He was as strongly of opinion that they were derivative, as he was that the Middle Glacial fossils were not so.

† This does not seem probable, as the borings in north-east Suffolk have revealed no Crag beds older than those of the Norwich zone.

‡ A similar view has been expressed by Mr. C. Reid, *Mem. Geol. Survey*, Cromer, p. 93, 1882.

How far the Middle Glacial sands represent, or may perhaps have been locally the cause of interglacial conditions in East Anglia, must be left an open question. No large erratics, implying the presence of floating ice in the North Sea at this stage, have, however, been met with in these beds.

THE UPPER GLACIAL DEPOSITS OF EAST ANGLIA.

The Chalky Boulder Clay, and the Plateau (Cannon-shot) Gravels.

Passing from the loams and brickearths of the region immediately to the north of Norwich to the great sheet of Boulder Clay which, coming on suddenly to the south of that city, extends, in a more or less continuous sheet, to the brow of the Thames Valley, one cannot but notice the striking difference between the two.

The Chalky Boulder Clay, the most important of the glacial deposits of East Anglia, has of late years received less attention from geologists, other than the officers of H.M. Survey, than those of the Cromer coast, possibly because the latter are more accessible, and because few good sections are now available in the former. One such, of considerable extent, may be seen, however, in a railway cutting at Forncett Junction, near the spot where the branch to Wymondham leaves the main line from Ipswich to Norwich.

The Chalky Boulder Clay covers an enormous area, as shown in fig. 15 (copied from a map published by S.V.Wood, Junr., in 1880),* extending from the north of Lincolnshire into Middlesex, and from Leicester to the East Anglian coast, more than 130 miles in each direction.

It is everywhere *sui generis*, and can be easily distinguished from other deposits; although its constituent materials vary greatly, according to the rocks over which the ice travelled, its

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* "The Newer Pliocene Period in England."—*Quart. Journ. Geol. Soc.*, vol. xxxvi, pl. xxi.

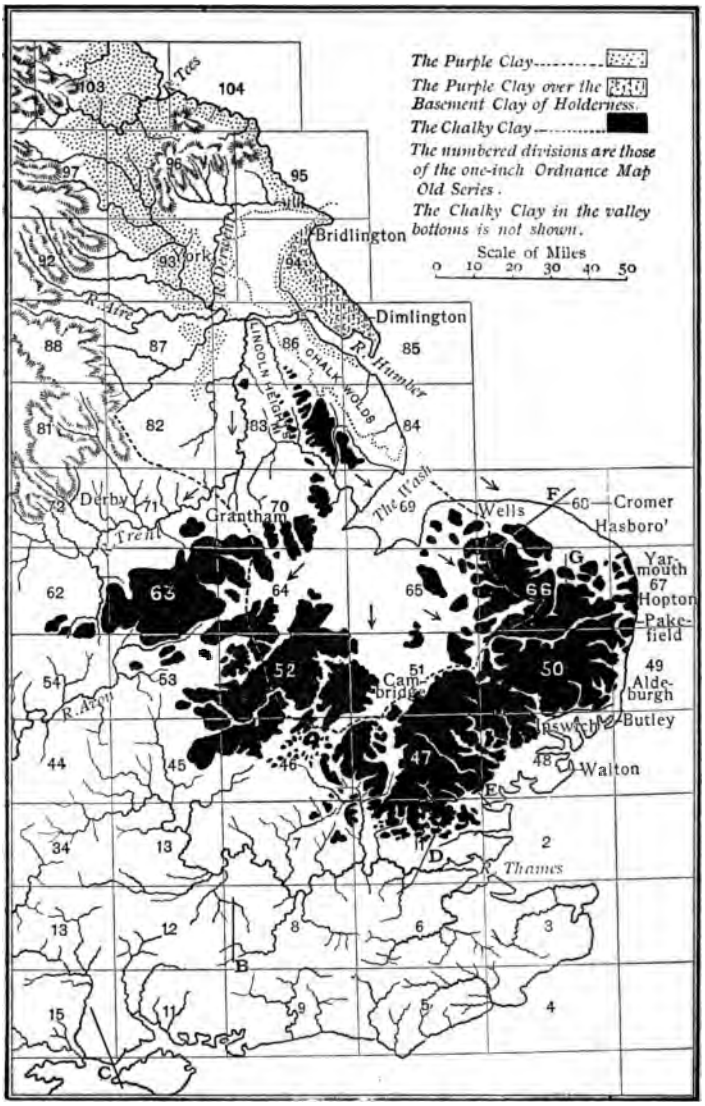

FIG. 15.—MAP SHOWING THE DISTRIBUTION OF THE PURPLE AND CHALKY BOULDER CLAYS OF THE EAST OF ENGLAND.

matrix being in places composed of blue Jurassic clay, as at Forncett, and at others largely of chalk, it presents the same general character, always containing abundantly minute fragments of chalk, in the same way that a cake is full of currants. Whatever the material the Chalky Boulder Clay mill had to grind, the finished product was the same. It is now generally believed to have been due to the action of land ice.

The material of which it consists has been derived from secondary strata, Cretaceous and Jurassic, and especially from the rocks present in Lincolnshire, Cambridgeshire, &c. Everywhere it includes fragments of hard chalk, and the white or grey flints of the former county; specimens of Red Chalk, Spilsby Sandstone, Kimeridge Clay, Coral Rag, Oxford Clay, and Lias may also be constantly recognised in it in different parts of the district.

In places the Chalky Boulder Clay rests on glaciated marly Chalk, the ice having apparently ploughed out any beds newer than the Chalk which may have there existed. Over the eastern part of Norfolk and Suffolk, however, it is underlain by the Middle Glacial Sands, which generally show no signs of disturbance at the junction of the two deposits, a fact which it is not easy satisfactorily to explain. The most reasonable hypothesis seems to be that given by S. V. Wood, Junr.,* who pointed out, on Nordenskiöld's authority, that the edge of the ice of Greenland and Spitzbergen is of no great thickness, and that it presents a low and shelving face as it approaches the sea, being preceded by a sloping bank of mud. He suggested that such a mud bank may also have been caused by and have preceded the ice stream which crept over East Anglia at this period. As the latter moved down from the higher land, much erosion of the soft Secondary rocks would take place, and the greater part of the eroded material would be pushed forward by the ice; when the ice sheet diminished in thickness, and the gradient along which it moved became less, not only would its eroding power become smaller, and eventually cease, but it would no longer be able to drive before it the whole of its moraine; some would be left behind to form a cushion, over which the thin edge of the advancing ice might move without disturbing the underlying strata.

The view taken by Wood and myself was that the Chalky Boulder Clay was in this way distributed over East Anglia by an ice stream, for which I propose the name of "The Great Eastern Glacier," which, fed by the snows of the Yorkshire Highlands, descended along the region covered by Jurassic rocks intervening between the Lincoln Heights, then possibly of greater elevation than now, and the Lincolnshire Wolds.† Getting clear of the hills, such a glacier might naturally have spread itself out like a fan, in the way suggested by the distribution of the Boulder Clay shown in fig. 15, moving towards Yarmouth in one direction, and Leicester in another. Still lying in considerable thickness over sheets 69, 64, 65, and 51, it would have ploughed out from that area the Kimeridge strata of which the enormous mass of the Boulder Clay covering East Anglia is largely composed, leaving when it eventually melted the great depression now occupied by the Fens. Continuing to travel outwards in all directions in an attenuated condition, the ice would have ceased to erode, but instead would have commenced to override part of its moraine, another part being still carried forward and spread out in a sheet, which became gradually thinner as it was moved further from its source.

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* *Quart. Journ. Geol. Soc.* vol. xxxvi, p. 487, 1880.

† Mr. R. M. Deeley states that at this stage an ice stream moved up the valley of the Trent from North to South, preventing the westerly extension of typical chalky clay. *Quart. Journ. Geol. Soc.*, vol. xlii, p. 457, 1886.

Other theories as to the origin of the Chalky Boulder Clay have, however, been advanced, and to those it is necessary briefly to refer. The one which has received the most support is that adopted by Prof. James Geikie, who, in a well-known work, gives a map, showing the Scandinavian ice at the time of its maximum extension, crossing East Anglia from the North Sea, in a N.E.—S.W. direction.* This conclusion seems to me untenable, however, in the face of the fact, shown above, that no Chalky Boulder Clay exists in the north-eastern part of Norfolk, between the Cromer and Hasboro' coast and Norwich, though it comes on suddenly immediately to the south of the latter place, along a line running at right angles to that of its supposed movement (see fig. 15). Even if we accept the view that the disturbance of the Contorted Drift was to some extent due to the North Sea ice during the Chalky Boulder Clay period, we must remember that such contortions become less numerous as we trace the Lower Glacial beds from the coast, and are unknown in the neighbourhood of Norwich.† The Rev. E. Hill, examining microscopically the matrix of the Suffolk Boulder Clay, has come to the conclusion that the Chalky Boulder Clay ice came, not from the North Sea, but from the west or north-west.‡ There is, however, no high land in the former direction, and it is difficult to imagine that any snowfield could ever have existed in the Midlands of sufficient extent and elevation to have produced the great ice-sheet which overspread the Eastern Counties. Mr. Hill, equally with myself, however, opposes the view that the Chalky Boulder Clay came from the eastward, expressing the opinion, taking matrix and inclusions together, that 99 per cent. of the material of which it is composed is of westerly and Secondary origin. It has also been supposed that the North Sea ice might have entered East Anglia through the gap now forming the Wash, and having done so, that it fanned out in all directions—to Yarmouth, to Middlesex, to the Midland Counties, and to North Lincolnshire. In order to furnish the *vis a tergo* to enable it to extend itself thus, it must have lain in great thickness off the Norfolk coast, but in that case, it would also have overridden north-eastern Norfolk, and have taken the more direct route towards Yarmouth, across sheet 68 (fig. 15). Moreover, on this view, it is not easy to account for the hard chalk, or white flints, or the boulders of Lincolnshire sandstone in the East Anglian Boulder Clay. Had the ice entered by the Wash, fanning out thence in all directions, such sandstone erratics would have been carried northward, and westward, towards Market Rasen, or Grantham, rather than into Suffolk.*

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* The Great Ice Age, 3rd Edit., pl. IX. p. 437, 1894.

† The disturbances near Norwich are due, as will be shown later on, to ice moving down the valleys, and not to ice coming across the county from the N.E. Disturbances, but of a slighter character, may be observed in places, however, in the Norwich brickearth.

‡ *Quart. Journ. Geol. Soc.*, vol. lviii, p. 179, 1902.

That the ice crossed the Wolds from the North Sea seems still more improbable. In that case some material like that of the purple clay which rests against their eastern flanks, should have been brought over with it. The boulder clay of Lincolnshire, to the west of those hills, however, is almost wholly composed of chalk.

Of these hypotheses, the one I adopt seems to present the fewest difficulties. To the north-west of East Anglia alone, high land exists adequate to produce the enormous glacier which overrode the region covered by the Chalky Boulder Clay. There also are to be found the various strata, Cretaceous, Oolitic, and Liassic, of which the great moraine is composed. If the ice came from this region, we must allow, however, in estimating the preglacial elevation of the latter, for the large amount of material since removed from it, but, apart from this, it seems probable that Lincolnshire may have stood relatively higher, during the Pleistocene epoch, than it does at present.

As the glacial period waned, and the ice melted off the higher parts of Norfolk and Suffolk, still lying in considerable though diminished volume over Lincolnshire and the Fen region, it seems to have shrunk into the valleys, some of which at least can be proved to have been occupied by streams of moving ice during the latter part of the Chalky Boulder Clay period. The excavation of many, perhaps of most, of these valleys commenced in glacial rather than in post-glacial times, although they may have been deepened by the floods which attended, and perhaps followed the melting of the ice. The numerous valleys by which East Anglia is furrowed, out of all proportion to its area, or to the streams which flow, or ever could have flowed in them, may thus represent gigantic striæ. It is perhaps worthy of notice that their general

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* My friend, Mr. H. B. Muff, F.G.S., has recently found, for example, in the boulder clay of a railway cutting near Haverhill, in west Suffolk, five large blocks of Spilsby sandstone, and Mr. Whitaker has identified the sandstone boulders of south-west Norfolk, including the well-known one at Merton, near Watton, as of Neocomian origin. *Mem. Geol. Surv.*, Attleborough, p. 10, 1884. Mr. Muff reports many boulders of gannister, Mill-Stone Grit, and Carboniferous Limestone, from the boulder clay of the neighbourhood of Cambridge. The latter are also more or less common in other districts.

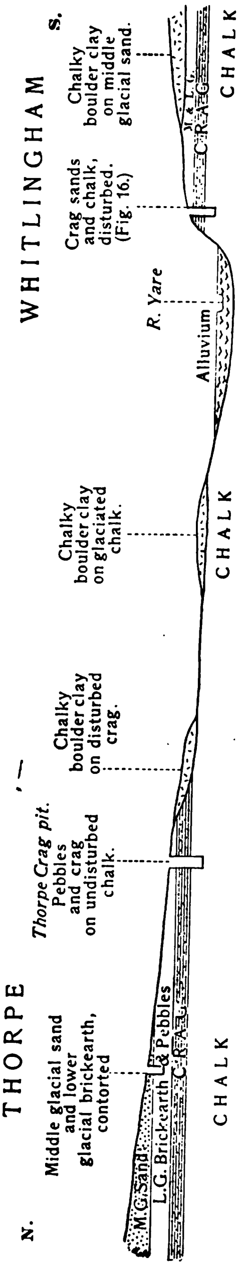
N.
THORPE
WHITLINGHAM
S.
Middle glacial sand and lower glacial brickearth, contorted
M.G.Sand
L.G. Brickearth
Pebbles
CRAG
CHALK
Thorpe Crag pit.
Pebbles and crag on undisturbed chalk.
Chalky boulder clay on disturbed crag.
Chalky boulder clay on glaciated chalk.
CHALK
Alluvium
R. Yare
Crag sands and chalk, disturbed. (Fig. 16.)
Chalky boulder clay on middle glacial sand.
M.&L.G.
CRAG
CHALK

Fig. 16.—Section across the Valley of the Yare, at Thorpe, near Norwich.

alignment coincides, more or less nearly, with the directions in which I suggest the ice may have travelled (fig. 14).

In a paper contributed to the Geological Society in 1866, I called attention to the fact, that Chalky Boulder Clay assumes the character of a valley deposit in the neighbourhood of Norwich.* Soon after, excavations for the Norwich Sewer Works revealed the existence of a mass of similar clay extending to an unknown depth below the sea level at the bottom of the Yare valley, just above its junction with that of the Wensum.† Many similar cases are now known to me, but there is one of special interest at Thorpe, near Norwich, to which I hope to call the attention of the members of the Association during their proposed visit to Norfolk, showing that the Yare valley was during the latter part of the Chalky Boulder Clay period occupied by a glacier of considerable size.

The valley at this spot has been excavated interglacially out of the Crag, and the older Glacial deposits (fig. 17).

Near the Lunatic Asylum, in the well-known Thorpe section, the Norwich Crag is shown to rest on undisturbed Chalk, the Crag being overlain higher up by Lower and Middle Glacial beds. The Crag may be also seen at Whitlingham, on the opposite side of the valley, at this point half a mile wide, resting on the Chalk, which, at one pit, is equally undisturbed. Within the valley, however, and but little above the level of the river, there is a pit of Chalky Boulder Clay resting on Chalk in a marly and glaciated condition. Nearly opposite the Asylum, on the Whitlingham or south side of the river, and not far from the last-named section, is another quarry where, forty years ago, the photograph from which fig. 17 is copied, was taken by the late Mr. Howes.[*] This section, showed that the Chalk and the sands overlying it had been violently disturbed, the lines of flint having been forced up into a sharp anticlinal disturbance. Moreover, on the north side of the river, and not far from the Thorpe Crag pit, the Lower Glacial Brickearth and the Middle Glacial sands have also been disturbed, while a recent road excavation near the Asylum, shows the Boulder Clay as a valley deposit dipping towards the Yare, and ploughing out the Crag beds down to the Chalk. These facts, all closely connected, and doubtless due to the same cause, show, I think, that at this stage of the glacial history, an ice stream more than half a mile in width, and, at least, a hundred feet in thickness, impinging on the Chalk with irresistible force, and producing the contortion portrayed in fig. 17, crept down the Yare valley on its way to the sea. I believe this example to be a typical and not an anomalous one. All who know the district intimately are

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* A Third Boulder Clay in Norfolk. *Quart. Journ. Geol. Soc.*, vol. xxii, p. 87, 1866.

† Intraglacial Erosion near Norwich. *Quart. Journ. Geol. Soc.*, vol. xxv, p. 445, 1869.

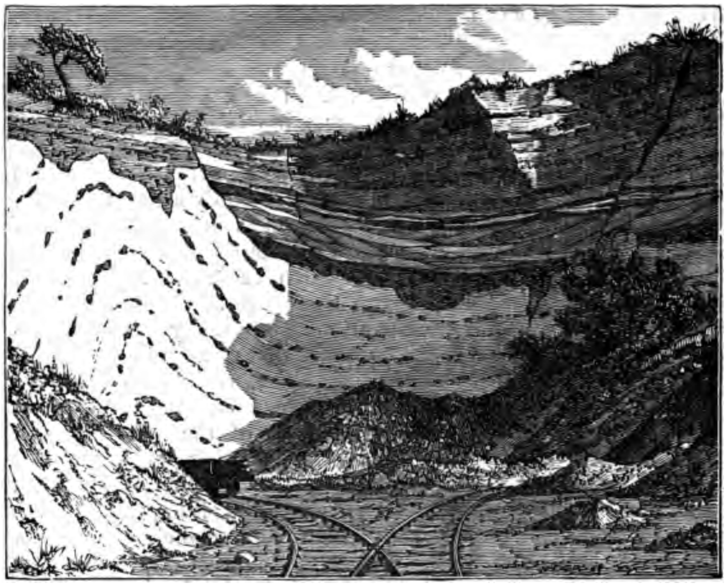

FIG. 17.—SECTION SHOWING THE DISTURBANCE OF THE CHALK, AND OVERLYING BEDS BY THE YARE GLACIER.

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[*] Reprinted from the "Geology of England and Wales," by the kind permission of Mr. H. B. Woodward.

familiar with the fact that the Chalky Boulder Clay seems constantly to plunge into the valleys.*

Of later age than the Chalky Boulder Clay, are some Plateau Gravels which occur at several places in the neighbourhood of Norwich, as at Mousehold Heath to the north of the city, where they rest on the Middle Glacial Sands, and at Strumpshaw, and Poringland, to the south and east, where they overlie the Boulder Clay. They are largely developed near Wymondham, and thence extend into central Norfolk.

Composed principally of flints, often of large size, they have evidently been accumulated under the influence of violent floods, representing the waning of glacial conditions in East Anglia, when the destructive and constructive agency of water was replacing that of ice. Similar gravels exist in north Norfolk, as at Holt, and to the south of Cromer. These, possibly belonging more or less to the same period, may have been connected with the North Sea ice, rather than with that to which the Chalky Boulder Clay was due. One interesting fact should be pointed out. The plateau gravels occur not infrequently along the sides of the valleys, great and small, sometimes at the very edge of the higher land by which they are bounded, as at several places near the River Waveney, which separates Norfolk and Suffolk, where they have been regarded as of "high-level" age, and older than the excavation of the valley. That this is not so, however, is shewn by the fact that Chalky Boulder Clay occurs within the valley of the Waveney, sometimes at a low level, as it does in that of the Yare. The most important instance of the kind, however, is that of the great sheet of Plateau Gravel of Mousehold Heath, standing on which one looks down on the river Wensum, and the City of Norwich, 150 ft. immediately below. At first sight it appears that the deposition of these gravels must have preceded the excavation of the valley; the Chalky Boulder Clay exists, however, as we have seen, at the valley bottom, within half a mile of this spot, while the disturbance of the Chalk, shewn in fig. 17, lies little more than a mile distant. It is true that the Mousehold gravels are not directly underlain by Boulder Clay, but there can be little doubt that they are of similar age to those of Strumpshaw, Poringland, and Wymondham, which are. It is clearly impossible that these flood gravels could have accumulated under the conditions which now exist, and we seem therefore driven to the conclusion, which we have before reached independently, that when this took place, the valley of the Yare was filled to the brim with ice.†

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* At Cringleford, for example, excavations in my own grounds have shown that Boulder Clay not only underlies the Pleistocene gravels of the River Yare, but that it occurs in patches at different levels on the sloping sides of the valley.

† Mr. F. T. Bennett points out that the Cannon-shot gravel never crosses the valleys. *Mem. Geol. Survey*, East Dereham, p. 31, 1888.

It will not be possible to deal here with the still later geological history of East Anglia, except in the most cursory manner. The subject of the surface denudation by which the district has acquired its present form is an interesting one, but it cannot now be discussed. It seems to me, however, to have been due to causes operating during and immediately succeeding the glacial epoch, of an entirely different character to those now obtaining.

The general contour of the land, everywhere undulating, or furrowed, except on the plateaux of hard, impermeable Boulder Clay, or on the heaths of absorbent sand, could not have been produced under present conditions however prolonged.

The valley gravels, moreover, as for example those exposed in the yard of the Great Eastern Railway station at Norwich (Thorpe), attain a height far beyond that of any floods which now occur. They could only have been deposited, moreover, at a time when the land stood at a relatively higher level than at present, since the bottom of the valley cut out of the Chalk, within which they rest, is considerably lower than Ordnance Datum. At Norwich, they have been traced to a depth of about 20 ft. below the surface of the alluvium, but the valley bottom slopes rapidly down stream. At Somerleyton, on the railway between Norwich and Lowestoft, for example, the surface of the valley gravels was only reached at a depth of 70 ft. below sea level.

While these gravels thus represent a period when East Anglia stood at a higher level than that of the present, being probably joined to the Continent, the deposition of the alluvial beds which rest on them was accompanied by a subsequent subsidence, during which the North Sea, reinvading its former basin, crept up the interglacially formed valleys, converting their lower reaches into estuaries. Estuarine conditions continue to this day in the southern part of East Anglia, as in those of the Stour and the Orwell. On the other hand, the valleys of the Bure, the Yare, and the Waveney, have been filled with silt or peat. The first-named are, in fact, in a condition of arrested development, the explanation of which may remind us of an interesting episode in the later geological history of the district.

The constant encroachment of the sea upon those parts of the East Anglian coast that are exposed to the tidal scour is a fact only too well known to the unfortunate owners of the land, the waste being as a rule greatest where the cliffs are high. So long as the latter are buttressed by the accumulation of talus, or by the accumulation of beach, they are safe, but when these are eaten away by the waves, and the cliff acquires a face more or less vertical, it falls by its own weight, its disintegration being hastened by the action of land-springs.* The fallen material

* The District Council of north-east Norfolk is at present perpetrating the almost incredible folly of removing quantities of shingle from the beach at Bacton for road mending.

protects it for a time, but eventually history repeats itself, and a further strip of land falls a prey to the hungry sea.

A considerable portion of the material derived from this waste of the land remains upon or near the shore, accumulating principally at comparatively sheltered spots. From another portion, however, has been formed those long narrow sand-banks which fringe certain parts of the coast, lying parallel to it, at no great distance from the land.

As is well known, the beaches of the eastern parts of Norfolk and Suffolk have a tendency to travel from north to south, the currents running in that direction, those of the flowing tide, being the stronger. Efforts are frequently made to arrest this coastal movement, and so to cause accumulation at certain points by the construction of groynes, but the protection of one spot is gained at the expense of other localities. Lowestoft affords a striking instance of this. The two long piers which enclose the harbour at that place form a gigantic groyne. Large quantities of sand are constantly accumulating therefore to the north of the north pier, a sandy plain now extending from the pier head to the foot of the cliffs (the sea margin of a former period) upon which the old town of Lowestoft stands. On the contrary, little or no sediment reaches the shore to the south of the south pier, and the local authorities, so far as they are there endeavouring to protect the cliffs by groynes, seem to be engaged in an unequal and hopeless struggle.

The amount of material available for the formation of beach is strictly limited, depending on the waste going on towards the north. Where the cliffs are composed of sand, the beaches lying to the south are more or less sandy; where of gravel, they are stony. An example of the latter state of things is presented by the great shingle bank (derived from the pebble beds of a former extension of Dunwich cliff, now destroyed) which extends southwards from Aldeburgh, in Suffolk. The river Alde, immediately to the south of that town, approaches the sea at right angles, until within about 100 yards of it. It then turns abruptly to the south, and runs parallel to the shore, and near to it, finally reaching the sea at Hollesley, nine miles to the south-west. It is the gradual travel of the beach southwards, and the accumulation of the great shingle bank of Orford Ness, between the river and the sea, that has altered the course of the Alde. Similarly the destruction of the cliffs of north Norfolk in former times has given rise to the great sand-bank upon which Yarmouth has been built. Until this bank had finally established itself across the mouth of the Yare estuary, the tidal currents kept possession of its V-shaped valleys, heaping themselves up inland at high water, where the latter became narrower, to a level higher than that of the sea outside. Were it not for the existence of this sand-bank, and the fact that the influx of the flowing tide is confined to the narrow channel of the river between Gorleston and Yarmouth, similar conditions would obtain at present.

The estuarine condition of the Norfolk vallies seems to have continued until a comparatively recent period, as suggested by Samuel Woodward in a map of Roman Norfolk published in 1833.[*] Such a view is supported by the positions chosen by the Romans for their camps, at Burgh, Caister, and elsewhere. There is an old map in Yarmouth (the Hutch map) which shows a similar state of things as existing even in Norman times. In the district known as the Flegg Hundred, a triangular area in East Norfolk, bounded by the River Bure and the Hundred stream, (fig. 14), most of the names of the villages end in *by*, a proof of their Danish origin, while the majority of those on the opposite bank of the Bure have Saxon terminations.[†] It would seem therefore from this that in those troublous times the Flegg Hundred may have formed a region marked off by some natural boundary, protecting its inhabitants from sudden attack. Moreover, the Saxon Chronicle states that in A.D. 1004, Sweyn, with thirty ships, plundered and burned Norwich, marching afterwards from thence to Thetford. The inference has been drawn that the failure of a Saxon attack on the ships, in the absence of many of their defenders, may have been due to the estuarine condition of the Wensum valley at Norwich at that period.

There is no evidence to show when the Yarmouth sand-bank began to accumulate. Originating first as a submarine shoal, it grew until, at some time previous to the Norman Conquest, it had become an island, frequented by fishermen. We learn from a survey made by Edward the Confessor, about A.D. 1050, reported in Domesday Book, that Yarmouth had then seventy burgesses. The sand-bank may at this time have obstructed, though it did not wholly prevent, the daily flow of the tidal water into the estuary.

This is further shown by the existence of *salinæ*, pans for evaporating salt water, which are recorded as having existed at that period at Halvergate and Cantley, in the Yare valley, and in the Bure, at Runham, South Walsham, and other places some miles inland.

The protracted struggle between the growth of the Yarmouth sand-bank and the scour of the tidal currents marks a stage in the history of the Broadland district. Gradually but irresistibly creeping southwards, it drove the mouth of the Yare before it. At one time the river reached as far as Corton, a few miles north of Lowestoft, but in the sixteenth century an artificial opening to the sea was made for it at Gorleston, two or three miles to the south of Yarmouth; its further progress towards the south is now barred by the piers at the latter place. Accumulation is taking place to the north of these piers, as at Lowestoft, and the cliffs to the south of them are wasting. All trace of the former channel of the Yare, for example, to the south of Gorleston, and between that place and Corton, has been destroyed by the encroachment of the sea.

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[*] Archæologia, vol. xxiii, p. 358, 1833.

[†] Thurne, Repps, and Bastwick, are also Danish, and possibly Runham and Martham, the latter being, in Mr. Walter Rye's opinion, corruptions of Runholm, and Martholm.

The conditions of the valleys of the Stour and Orwell; of the Alde; and of those of the Bure and the Yare, may thus represent successive stages in the process by which the Broads have acquired their present features. The first named are still open to the sea because a smaller amount of material derived from the waste of the coast immediately to the north is there available. Similar causes are at work, however; a sandy spit extends southwards from Felixstowe towards the mouth of the estuary of the Stour, and many submerged sand-banks exist in the offing. The access of the tidal currents to these valleys is, however, for the present unobstructed.

For a long time the river Bure kept for itself an opening to the sea to the north of Yarmouth, but this was finally silted up in the fourteenth century. With the exclusion of the sea from the estuary by the blocking of its northern mouth, and of any similar opening which may have existed between Horsey and Winterton, along the Hundred Stream depression, the final stage in the evolution of the Broads commenced. Towards the sea, sediment, consisting partly of mud brought down by the rivers, which are turbid when in flood, and partly of tidal silt, was deposited in sheltered places as banks or shoals. Such deposition is still going on, as, for example, in Breydon Water, over the mud flats of which, as Mr. A. Patterson informs me, a small boat can hardly pass now, where thirty-five years ago a wherry could sail.

Further inland, beyond the point to which the tidal waters could penetrate, aquatic vegetation flourished in the water-logged soil, and along the banks or the shallower parts of the streams.

The first effect of the exclusion of the swiftly flowing tidal currents from the valleys of the Norfolk Broadland was to transform all the land below a certain level into a sheet, or possibly into several sheets of inland water, which gradually became smaller, and were finally reduced to a series of lakelets, by the deposition of mud, and the accumulation of decaying vegetation.

At a later stage, and by a similar process, impassable swamps became meadows, and cattle now graze in the former haunts of the crane and the bittern.*

From the valleys of the Waveney, and the Yare, fresh water lakes have nearly disappeared.* Marshes protected from inundation by river banks, during the summer at least, extend from Norwich and Bungay, to Yarmouth and Lowestoft. Along the Bure, however, Broads still exist, occupying possibly the deeper parts of the old valley, the holes which have not yet been filled up. The agencies by the operation of which they came into existence are still at work, and will eventually bring them to an end, the more quickly perhaps because the rivers, the current of which tends to keep their own channels open, do not run through the Broads, but past them.†

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* Breydon is the shrunken representation of the large sheet of water which must at one time have covered the low ground shown in the map (fig. 14), extending from Yarmouth, to beyond Reedham in one direction, and Acle in another.

A portion of the Broadland, that traversed by the Hundred stream, once open to the sea, is now protected from its incursion by hills of blown sand, and by the sandy beach accumulating at their base. The sand dunes at this spot are gradually moving inland, the sea following. When Sir Charles Lyell visited Norfolk in 1839, he found the ruined church tower of Eccles (a small village on the coast, to the south-east of Hasboro') half buried in the sand hills.‡ Twelve years afterwards, the latter having shifted, it stood to seaward of them, and it has since been entirely destroyed by the waves. Compared with the enormous dunes of some parts of the Dutch coast (two miles in width, for example, in the island of Texel), our own sand-hills afford a less secure protection to this part of the Broadland than could be desired. Much of the land is there below the level of high water, and were a breach in the cliffs once made the sea would take possession of the lower reaches of the Bure valley, and again convert the old Danish settlement of the Flegg Hundred into an island. It is probable that the safety of the district depends as much on the stability of the beach at this point as on that of the sand-cliffs, but step by step the sea is gaining on the land, and it is to be feared that nothing can permanently prevent its continued encroachment.

The time allowed for writing the second part of this paper has been so short, its immediate publication being required for the use of the Members of the Association taking part in the proposed excursion to East Anglia, that it has been impossible to read up the voluminous literature of the subjects with which it deals. My apologies may therefore be due to some whose published opinions, whether in agreement with my own or not, deserve a fuller notice or recognition than I have been able to give to them.§

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* The Broads of Rockland and Surlingham in the latter are gradually disappearing.

† A comparison of the recent maps of the Ordnance Survey with those issued half a century ago will show that the Broads, taken as a whole, have been considerably reduced in extent during recent years

‡ *Principles of Geology*, 10th Edit., vol. i, p. 513. Mr. Walter Rye informs me that a patent for the erection of this church on a new site was granted in 1338, the one formerly existing at Eccles having been destroyed by the sea.

§ My thanks are due to the Council of the Geological Society of London for permission to reproduce some of the diagrams accompanying this paper.

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Mr. H. B. Woodward has, moreover, recently published an interesting paper on the Geology of Norfolk, with a geological map of the county on the scale of one inch to four miles, showing the Glacial as well as the older deposits, to which reference should be made. (*Victoria History of the County. Westminster*, 1901.)

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